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A submarine fantasy, which in spite of the mermaids and the disproportion of the figures gives an excellent impression of some animal forms of West Indian waters. By A. H. Baldwin

SHELLED INVERTEBRATES OF THE PAST AND PRESENT

WITH CHAPTERS ON

GEOLOGICAL HISTORY

By

RAY S. BASSLER

CHARLES E. RESSER

WALDO L. SCHMITT

PAUL BARTSCH

VOLUME TEN

OF THE

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1931

EDITOR'S FOREWORD

The chapters on Geological History, which begin this volume, cover a wide field. The editors feel that such a survey of the earth's history as that prepared by Doctors Bassler and Resser constitutes a valuable background to all the volumes of the present series which deal with biology; and in view of the extent to which our knowledge of historical geology, especially of the Paleozoic Era, depends upon fossil shells, this volume seemed to be the most appropriate place for the survey.

The two authors have combined their chapters to make a continuous story, with the result that Doctor Resser's section—Chapters III, IV, and V—appears in the middle of Doctor Bassler's section, he being responsible for Chapters I, II, VI, and VII.

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GEOLOGICAL HISTORY OF NORTH AMERICA

By

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CHAPTER I

COMPUTING GEOLOGICAL TIME

How old is the earth? This question has perplexed mankind for many generations, but not until comparatively recent times have we turned to the earth itself for an answer. Today, although the estimates of geologists differ widely, all are agreed that the history of our planet is to be measured in millions if not hundreds of millions of years.

Darwin was among the first to devise a strictly scientific method of solving the vexed question of the earth's antiquity. He recommended that we observe the work of rivers and of the sea; that we note how a stream will wear away the land along its banks and will carry the soil to be deposited in the lowlands and spread out at its mouth; and how the waves of the sea, cutting into a cliff, will carry the débris thus worn away to some quiet place along the shore and there lay it down, where ultimately it will form solid rock.

Many things lead us to believe that in the long-distant past rocks were formed precisely in the same manner as we now see them being formed. For example, we note that many rock strata consist of the same materials as the sandy shores of the ocean or the mud and clay banks of the rivers. We also observe that these rock strata are arranged in beds such as are now being laid down. In

fact, the only difference between the sedimentary rocks and our present-day deposits of sand and clay lies in the fact that the former have solidified. Moreover, we discover sand deposits in all stages of consolidation, from soft, movable material, through a half-compacted substance, to hard, gritty sandstone.

Accepting this principle of the formation of rock, the next step in determining the age of the earth is a matter of measurement. Such measurements in the Nile Valley, where there is great regularity in the deposits made by the river, indicate that it takes the Nile a hundred years to lay down a bed of mud thirty-four inches deep.

Now, we have more than 350,000 feet of sedimentary rock known to have been laid down in just this manner, from the beginning of sedimentation to the present time. At the rate of about a third of an inch a year, the time required to deposit this thickness of seventy-five miles would be at least twelve million years.

This estimate, however, takes for granted that the 350,000 feet of sedimentary rock have been laid down with the precision and regularity of clockwork; that is, that .34 inch of sediment has been laid down every year unceasingly since the first streams ran down to the first seas. But natural processes are seldom so simple as that. Recent researches tend to show at least two elements of unreliability in the stratigraphic time clock. In the first place, the many known gaps in the record represent varying periods of time that are practically incalculable; and in the second place, it has been shown that because of changes in climate and in the elevation of the land the rate of deposition has varied greatly through the ages and is probably much swifter today than during many of the earlier epochs. So the twelve million years computed on this basis must be regarded merely as the irreducible minimum of the number that the earth has seen.

Another method of estimating the earth's age is based on the rate at which, by the combined action of many

natural forces, the material for the sedimentary deposits has been torn from the mountains and elevated plateaus. Through such agencies as wind, water, and ice a plateau or mountain chain, after being uplifted high above sea level by the internal stresses of the earth, is gradually worn down again to sea level, thus completing its "life cycle."

Plateaus soon after they are uplifted begin to be dissected by numerous streams, until they ultimately take on the appearance of mountains. This phenomenon may be seen in the Cumberland Mountains, which are but the edge of the Appalachian Plateau. Through the continued work of the erosive elements these mountains will eventually be worn down to sea level, below the reach of the erosive power of storms. It is at this stage, as seen today in the Laurentian Shield of Canada, that mountains are said to have reached "old age"—when, in fact, they have ceased to exist as mountains.

Slow as this process must be, certain mountain systems bear indications of having passed, not once but several times, through the cycle of uplift, erosion, and final leveling. We may gain some idea of the ages consumed in effecting such changes by noting the rivers that have held their courses unchanged across a region of uplift, cutting into the plateaus and mountains as fast as the land has risen. Observing how very slowly streams wear down new channels, we may conjecture how great a length of time it takes for mountains to rise. Although we have no way of computing with any exactness the time required for such vast changes, we may readily see that it would represent a period beyond human comprehension.

A more exact method of estimating the earth's age proceeds from a calculation of the percentage of salts in sea water. In the earth's infancy the water now forming the ocean, as well as that forming the rivers, lakes, and snow fields of the land, existed as vapor; and with it were

mingled many other gases, the whole forming a vast atmosphere surrounding the still intensely hot globe. With the gradual cooling of the globe the vapor condensed and fell to the earth as rain. Professor Joly has estimated that the proportion of salts in the primeval ocean was about 10.7 per cent of the amount found in the ocean today. The remaining 89.3 per cent of the present total has been washed out of rocks and carried down in solution to the sea by rivers. The amount of the accession each year and the total amount of salt now in the ocean have both been estimated, and these estimates permit an age of about a hundred million years to be computed for the earth.

The reliability of this method, however, is open to question, as Prof. J. W. Gregory has pointed out. In the first place, he claims, the oldest fossils indicate that the seas were practically as salt in ancient times as they are now, the contrast between fresh-water and salt-water animals being as sharp in the Paleozoic era as it is today. Secondly, Professor Gregory finds that the method in question makes no allowance for the large supplies of salt raised from beneath the earth's surface by volcanic action. And, finally, he objects to the assumption of a uniform rate in the absorption of salts from the rocks and soil by the rivers, and regards it as probable that at the present time the rate is greater than the average. He concludes that this accelerated rate alone would justify multiplying the estimated age of the earth by 5. Professor Gregory's final conclusion[1] is that "the best-known geological estimates of the age of the earth require to be multiplied ten or twenty-fold in order to agree with the physical estimates, but this increase is consistent with the geological evidence."

It is to the physicists that we must turn for the most recently devised and perhaps the most accurate geological time clock. This is nothing less than the rate at which a

[1] The Age of the Earth. Ann. Rep. Smithsonian Inst. 1921 (1922), p. 259.

radioactive mineral, such as uranium, disintegrates or "decays"—a process so slow that a grain of radium can produce only an infinitesimal fraction of its weight in lead per year—a twelve billion two hundred millionth part of a gram. Of this process Lord Rayleigh says:[1]

> . . . Uranium, for example, goes through a series of changes (radium is one of the stages in its progress), changing eventually into an isotope of lead—that is, an element chemically indistinguishable from lead, except by a slight difference of atomic weight. . . . The isotope of lead in question has probably an atomic weight of 206 exactly, as contrasted with an atomic weight of 207.1 for ordinary lead. This is much less than the atomic weight of uranium (238.5), and the difference represents approximately the weight of helium atoms, which are the débris shed at the various stages of the transformation. . . .
>
> . . . It would seem that in the disintegration of a gram of uranium we have a process the rate of which can be relied upon to have been the same in the past as we now observe it to be. . . .
>
> If all the lead were uranium-lead, and had been generated since formation of the earth's crust, the time required would be 11×10^9 years. This is certainly too great. Allowing for the production of some of the lead from thorium, Russell finds a period of 8×10^9 years as the upper limit. This is about six times the age indicated by the oldest individual radio-active minerals that have been examined.
>
> . . . The upshot is that radio-active methods of research indicate a moderate multiple of 1,000,000,000 years as the duration of the earth's crust as suitable for the habitation of living beings. . . .

This figure has been confirmed by Dr. Harold Jeffreys in a calculation based on purely astronomical data. He estimates the time needed to bring the planets into their present orbits as "of the order of 8×10^{16} sec. or 2.5×10^9 years, agreeing with the estimate given by the uranium-lead ratios."[2]

We might then conclude that our earth has had a history of at least two billion five hundred million years. But one or two dissenting voices object to this estimate: they say there is doubt as to whether the uranium clock has been keeping uniform time. If it has not, then the problem of age still remains to be settled.

[1] The Age of the Earth. Ann. Rep. Smithsonian Inst. 1921 (1922), pp. 251–254.
[2] The Age of the Earth. Ann. Rep. Smithsonian Inst. 1921 (1922), p. 260.

In any event it is certain that the earth's years must be measured by the hundreds of millions as the time clock in Figure 1 indicates. And this is the fact we have sought

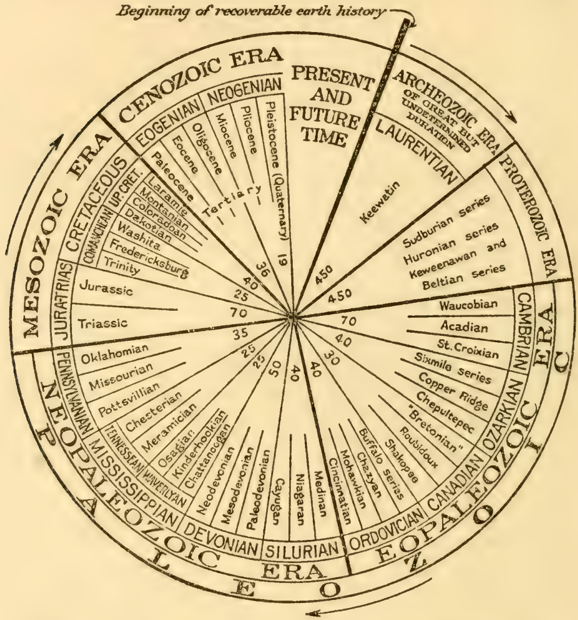


FIG. 1. Geological time clock, showing the eras, periods, and epochs to which the various rocks of the earth's crust are assigned. The figures in the center indicate, in millions of years, the estimated duration of each of the major divisions of time. Ulrich, 1915

to emphasize in order that the ancient life we are about to describe may be seen in its true perspective.

Our story takes us back to the earliest stages in the formation of the North American continent. In that

PLATE 1

View in the Grand Canyon, showing strata of Paleozoic age still in the position in which they were laid down. Archeozoic and Proterozoic strata crop out in the lowest depths only of the canyon

distant past, even as today, the streams and rivers flowing to the seas carried with them an immense burden of mud and sediment washed away from near-by lands. Then, as now, the sediments, softly settling on the sea bottom, buried many plants and animals, the hard parts of which, in the course of ages, became petrified, or, as we say, "turned to stone."

Today we find many of these petrifactions, inclosed no longer in soft mud beds at the bottom of the sea, but in uplifted solidified rocks that now form a part of the continent itself. It is chiefly by means of such fossilized plants and animals that we are able to spell out laboriously the ancient history of the earth.

Just as in the written history of the human race we distinguish three grand divisions of time—ancient, medieval, and modern—so the history of life in geologic time, covering many millions of years, may be separated into somewhat similar divisions—primeval, middle, and recent. The geologist has given to these grand divisions or eras, definite names, in order that the same terms may be used and understood by people of all languages. The most ancient life he calls *Paleozoic;* the middle life, *Mesozoic;* and the recent life, *Cenozoic.* Preceding the Paleozoic, he distinguishes two eras, the *Archeozoic* and the *Proterozoic*, both practically devoid of actual fossil remains.

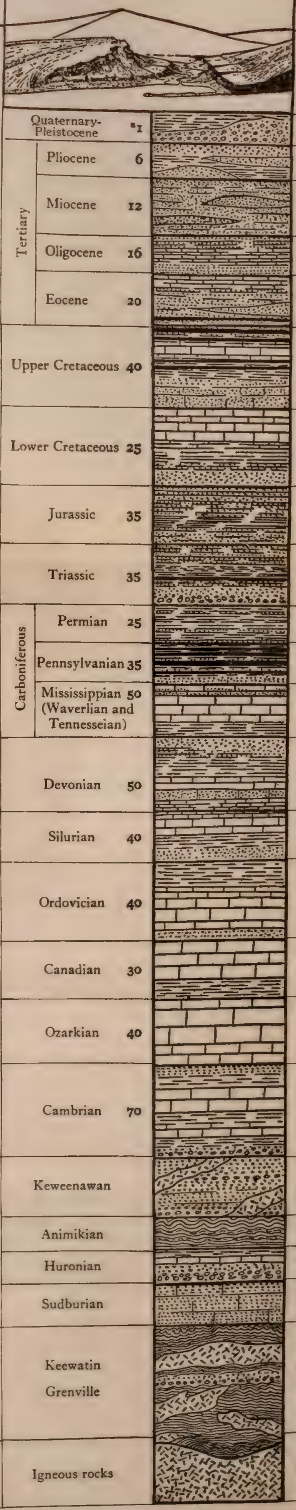
We call North America the New World; but since this continent was the first to emerge from the sea in its present form, remaining practically unchanged in general outline ever since, in geological history it is really the Old World. The other continents—Europe, Asia and Africa—which are of more recent birth, represent, therefore, the New World of geological history. Throughout the millions of years since the North American continent first emerged from the sea portions of it have been repeatedly engulfed by the oceans, wherein thick sediments of mud, sand, and limestone have been deposited. In consequence of these

deposits, the broad areas now elevated above the oceans preserve a total of several hundred thousand feet of sedimentary rocks containing the remains of numerous animals and plants of the past. Thus it is that our continent is the ideal one for the study of geological history, especially of the Paleozoic era—that of primeval life. Europe and Asia, which did not assume definite form as continents until the late Mesozoic and Cenozoic eras, are best fitted for the study of these more recent divisions of geological time.

At no place on the earth's surface has there been a continuous deposit of sediments from the earliest to the present time; for when one part of the earth was under the sea and thus receiving sediments another part was at the same time above the water, forming the land from which the sediments were eroded. At a later time conditions would be reversed; the beds which had previously been covered by the seas would form the land, and the former land mass would be covered by the sea. But by studying all the strata of sedimentary rocks that are exposed in the different regions of the world, geologists have been able to construct an ideal section of the earth's crust in which all the rock formations from the beginning of the earth's history to the present time are represented in chronological order. This ideal section is known as the geological column. Though only a small part of it may be studied at any one locality, in exceptional areas fairly large sections of the earth's crust are exposed. In the Grand Canyon of Arizona, for example (Plate 1), the Colorado River has cut through all the strata of the Paleozoic era and through many of those of the Proterozoic and Archeozoic eras. Although the strata of these three eras are not as thick here as in many other parts of the globe, over a mile of the column is visible.

If the layers of sedimentary rock formations dating from the beginning to the present time could be piled one on top of another, they would make a column over

DIAGRAMMATIC SECTION OF EARTH'S CRUST



ERAS OF GEOLOGIC TIME WITH CHARACTERISTIC LIFE		Epoch / Period	Duration[a]	CHARACTERISTIC ROCKS WITH MAXIMUM THICKNESS	
Age of man				Alluvial deposits	
CENOZOIC ERA (Modern life) Age of mammals and modern plants 55 million years		Quaternary-Pleistocene	1	Shale, sand, gravel	
	Tertiary	Pliocene	6	Clay, shale, gravel, sandstone	5,000 ft.
	Tertiary	Miocene	12	Shales, sandstones, limestone	14,000 ft.
	Tertiary	Oligocene	16	Shales, sandstone, limestone	6,000 ft.
	Tertiary	Eocene	20	Limestone, sandstone, coal beds	8,000 ft.
MESOZOIC ERA (Medieval life) Age of reptiles 135 million years		Upper Cretaceous	40	Sandstone, shale, limestone, coal beds	20,000 ft.
		Lower Cretaceous	25	Limestone, shale, sandstone	20,000 ft.
		Jurassic	35	Sandstone, shale	10,000 ft.
		Triassic	35	Sandstone, shale, coal beds	15,000 ft.
PALEOZOIC ERA (Ancient life) Age of invertebrate animals 380 million years	Carboniferous	Permian	25	Sandstone, shale	7,000 ft.
	Carboniferous	Pennsylvanian	35	Sandstone, shale, coal beds	10,000 ft.
	Carboniferous	Mississippian (Waverlian and Tennesseian)	50	Shale, limestone	4,500 ft.
		Devonian	50	Limestone, sandstone, shale	12,000 ft.
		Silurian	40	Sandstone, shale, limestone	6,000 ft.
		Ordovician	40	Sandstone, limestone, shale	6,000 ft.
		Canadian	30	Limestone, shale	4,000 ft.
		Ozarkian	40	Massive limestone	6,500 ft.
		Cambrian	70	Quartzite, sandstone, shale, limestone	18,000 ft.
PROTEROZOIC ERA (Primitive life) Age of primitive plants (algae) 450 million years		Keweenawan		Conglomerate and sandstone, with lava flows	30,000 ft.
		Animikian		Banded slates and cherts, with iron ore	14,000 ft.
		Huronian		Glacial conglomerates, quartzite, limestone	10,000 ft.
		Sudburian		White quartzite	20,000 ft.
ARCHEOZOIC ERA (Primal life) Age of unicellular life 450 million years		Keewatin Grenville		Sedimentary schist and gneiss, with lava flows; slates, conglomerates, limestone	100,000 ft.
PRIMITIVE CRUST		Igneous rocks		Granite and other igneous rocks	

[a] Figures give estimated duration of epochs and periods in millions of years.

seventy-five miles high. This geological column, or time scale, with its subdivisions, the kind and thickness of the rocks, the forms of life characterizing the major units, and the estimated number of million years' duration of each is shown in the table on the preceding inset. Reference to the geological column shows that the Archeozoic strata rest upon the primitive crust of the globe, which is seldom, if ever, seen at the present surface, because it is either concealed by the sedimentary rocks laid down upon it during long ages, or so changed by heat and pressure as to be unrecognizable. This primitive crust is composed of cooled lava, granite, and many other rocks of glassy or crystalline texture, which because they were formed by fire, or at least great heat, we term *igneous* rocks.

CHAPTER II

PALEONTOLOGY, THE SCIENCE OF FOSSILS

THE term *fossil* originally meant anything dug from the earth, including ordinary minerals and rocks. In the course of time the meaning of the word has been narrowed down, until now when we speak of fossils we refer only to those animal and plant remains, or traces of them, which have been preserved in rocks by natural methods.

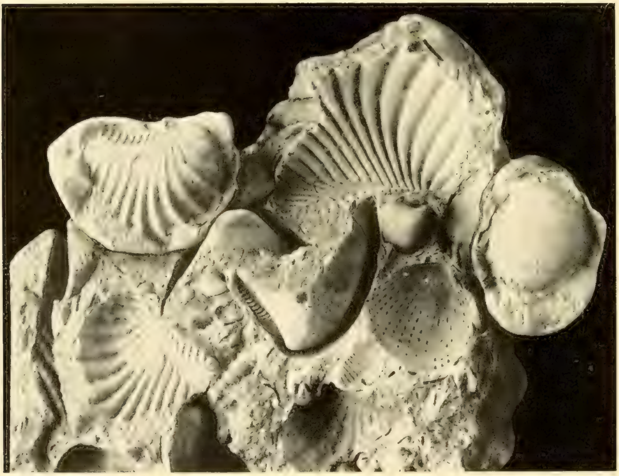
Not all kinds of rocks contain fossils. There are certain formations in which it would be quite useless to look for evidences of past life. Igneous rocks, for example, are formed of material which has been subjected to such great heat and pressure that it has become molten; and in this state it has either poured out from volcanoes and spread over the surface of the earth or has intruded itself into the underground layers. In some localities such intrusions have domed up the overlying strata; and after many years the top layers have been worn away, revealing such granitic masses as Stone Mountain, Georgia, and the Black Hills, South Dakota. It is clearly evident that even if these igneous rocks had once contained animal and plant remains, all traces of them would have been entirely obliterated by the great heat and pressure they have since undergone.

Some types of volcanic rocks formed of ash and the coarser material known as tufa may, and often do, contain fossils in a perfect state of preservation. Certain formations in our Western States are made up of tufa, and these have furnished specimens of fossils which are now the pride of museums. Not only the larger species of animal and vegetable life, but even delicate insects

Museum exhibit and its source

Upper: View along Chenoweth Creek, near Louisville, Kentucky, showing stratified rock of Early Silurian age. Lower: A section cut from the rock shown above and now in the National Museum. This rock is mainly limestone, composed of calcareous remains of marine animals cemented together

PLATE 3



Aspects of fossilization

Upper: A modern leaf and a fragment of newspaper, recently incased in a deposit of limestone. Lower: A fragment of fossiliferous sandstone, showing molds left by fossils that have dissolved; also, casts of two of the molds, which show the actual form of the dissolved fossils

and plants are often preserved most exquisitely in these deposits.

The majority of fossils, however, are found in the deposits of clay, lime, and sand that form the sedimentary rocks (Plate 2) of today. These sediments were originally deposited in the rivers and lakes, along the edges of the ocean, and in the fine ooze of the deeper sea waters. In the strata laid down by rivers and lakes we may find the remains of animals and plants that lived along their borders, as well as those that inhabited their waters.

Land animals and plants may be preserved also in deposits of wind-blown dust and sand, known as loess, which sometimes reaches a considerable depth; or they may be petrified in the lime deposits of fresh-water springs. The latter process is often quite rapid and may be observed today, as illustrated in the upper half of Plate 3. This shows present-day leaves and a newspaper preserved in lime, which was deposited about them by a spring into which they had been blown. As distinguished from the beds formed under the sea, deposits laid down by rivers, springs, and lakes and deposits of wind-blown sand are known as continental deposits.

Conditions in the sea are more conducive to the preservation of fossils than conditions on the land, so that fossils of marine plants and animals are of much more frequent occurrence than are those of continental species. We have, therefore, a much more perfect and complete record of the life of the sea than of the life of the land. By piecing the record together, however, we may get a fairly comprehensive view of the whole.

Not all fossils represent the actual bodies of animals. Sometimes the body remains have been dissolved out of the rock by percolating waters, and only holes or molds are left to represent them. Gutta-percha impressions of such molds (Plate 3, lower) give excellent reproductions of the original fossils. Again, the soft mud may have retained not the animal itself, but merely the imprint

of its body or of part of its body—perhaps only a footprint or a worm trail (Plate 4). These impressions, remaining in the hardened rock, often indicate quite clearly the nature of the creatures that made them. Such are the impressions of the grasshopper and the water skipper shown in Plate 5. Plate 6 illustrates how delicately perfect such impressions may be, as shown by the tsetse fly and the insect galls on the fossil leaf.

In the earliest geological formations actual plant remains are extremely rare. In the remote periods when these formations were laid down none but marine forms of life had as yet appeared. The seaweeds, although we have reason to believe that they flourished in great abundance even then, were too fragile and gelatinous to leave so much as an imprint on the sedimentary deposits of the time, except under rare conditions. In later periods the pithier nature of the plants made it possible for them to leave lasting impressions in the rocks. A leaf imprisoned between two layers of mud may be discovered today, on splitting open the hardened rock, as a thin film of charcoal. When this is blown away, the imprint of the fragment may be seen etched in delicate tracery on the split surfaces of the rock. Some of these impressions show the details of the leaf quite perfectly, especially when the grain of the rock is smooth and fine (Plate 6).

The pithier parts of plants, such as stems, seeds, tree trunks, and pieces of wood become petrified in the same manner as do most animal remains. As the organism slowly decays it is replaced molecule for molecule by mineral matter. When the process is complete nothing of the original plant or animal remains except its shape, which under favorable conditions is preserved to the minutest detail. Even the microscopic cells of petrified wood may be seen in thin sections of the fossil as easily as in the living plant.

The coal mines of England and France and those of Illinois have yielded another type of fossil in the form of

PLATE 4

A slab of Potsdam sandstone which was cut from a rock formed by the solidifying of a sea beach of early Paleozoic time. The ripple marks are crisscrossed by the trails of some wormlike animal. In the National Museum

PLATE 5

Impressions of insects in the celebrated lithographic limestone of Bavaria, which is of Jurassic age. Upper: A grasshopper. Lower: A water skipper

rounded balls, or *concretions*, which consist of a wonderfully well-preserved though tangled mass of fragmentary leaves, stems, and spore cases. The exquisite preservation shown in these so-called "coal balls" is the result of a process by which the original material of the plant has been entirely replaced by calcium carbonate. Here again the transformation from organic to inorganic matter has been so perfect that thin sections of the coal ball reveal all the detailed structure of the original plant. It is evident that a study of these concretions gives a more reliable knowledge of the plant life of the "Coal Measures" than any other method, and for this reason paleobotanists are constantly on the lookout for new occurrences of them.

The Rise of Paleontology

Long before the real significance of fossils was understood, their occurrence had aroused much discussion and speculation. Many extraordinary theories were advanced to account for the presence of these strange sculptures in the rocks.

The ancient Greeks and Romans rightly supposed fossils to be the remains of plants and animals; but they wrongly explained their occurrence on high mountains by assuming that the sea had once been deep enough to cover the heights, not recognizing the possibility that the land itself might have risen so far above sea level.

The science of the pagan world, however, instead of progressing normally to an ever more exact knowledge of natural phenomena, was overwhelmed by the ignorance and superstition of the Middle Ages. The medieval church frowned upon all who believed that the earth had existed for more than six thousand years, the limit supposed to be fixed by the Scriptures. A ridiculous controversy over the real nature of fossils, beginning in the fifteenth century, lasted for three hundred years; and even today the subject is still hazy in the minds of many. There were some who believed that fossils were the works

of Satan, intended to mislead mankind; others regarded them as mere freaks of nature; and still others considered them nature's unsuccessful attempts to reproduce living matter. Even those who believed that fossils represented the remains of ancient life thought it necessary to attribute their widespread distribution to the Flood. A special group of people, known as the "diluvialists," insisted, indeed, that the Deluge of Noah had caused fossils to be scattered through rock strata several hundred thousand feet thick. Since their views were in accord with medieval theology the diluvialists had the best of the argument for many years. Nevertheless, learned men arose to combat them.

That extraordinary genius, Leonardo da Vinci—eminent alike as artist, architect, and engineer and a pioneer in many other lines of endeavor—had occasion to study the fossils found in the rock strata of northern Italy through which his men were digging canals. These fossils, he proved conclusively, were the remains of marine life which had been brought in by the sea in past ages. This hopeful beginning, however, was checked by the German mineralogist, George Bauer, styled the "Father of Metallurgy," who declared that fossils were merely minerals. As late as 1699, Edward Llhuyd, an Englishman, advanced the theory that moist ocean vapors transported seeds and, penetrating into the rocks, planted them there to germinate into fossils.

However, after a long and hard struggle, there came into existence the modern science of paleontology, which, through its revelations of the past life of our planet, has played so important a part in the development of the larger science of geology.

It is by means of the fossils they contain that the relative age of the various rock formations in different parts of the world may best be determined. Physical phenomena, such as rainfall, weathering of rocks, and deposition of sediments under water, have remained

essentially the same throughout the earth's long life; therefore, even when we find an orderly record of these processes in various rock strata, we still have no means of knowing at what particular period of the earth's history the deposits were laid down.

The life of the past, however, furnishes a guide for the division of time since the beginning of the earth's history into geological periods. For the species of animals and plants in the world do change, though very slowly, in the course of long ages. It is definitely known that the simplest forms of life are found as fossils in the oldest stratified rocks, and, also, that the degree of complexity of the species occurring in any stratum of these rocks is in inverse proportion to the age of the stratum; that is, the more recent the stratum the more complex are the species represented by the fossils it contains. This is graphically represented in the table that follows, which shows the major divisions of geological time, together with the progress of plant and animal development in each. It is also a well-founded conclusion that sedimentary rocks in different parts of the world which contain the same kinds of fossils were deposited at practically the same time.

MAJOR DIVISIONS OF GEOLOGICAL TIME SHOWING DEVELOPMENT OF PLANT AND ANIMAL LIFE

ERAS	PERIODS	ADVANCE IN PLANT LIFE	ADVANCE IN ANIMAL LIFE
Cenozoic	Recent	Highly developed forms of all plants	Age of man
	Pleistocene	Age of modern plants	Extinction of great land mammals
	Pliocene		Age of man-apes
	Miocene		Culmination of mammals
	Oligocene		Rise of higher mammals
	Eocene		Primitive mammals
Mesozoic	Upper Cretaceous Lower Cretaceous	Rise of flowering plants	Culmination of great reptiles
	Jurassic	Age of cycads	Rise of flying reptiles and birds
	Triassic		Rise of dinosaurs

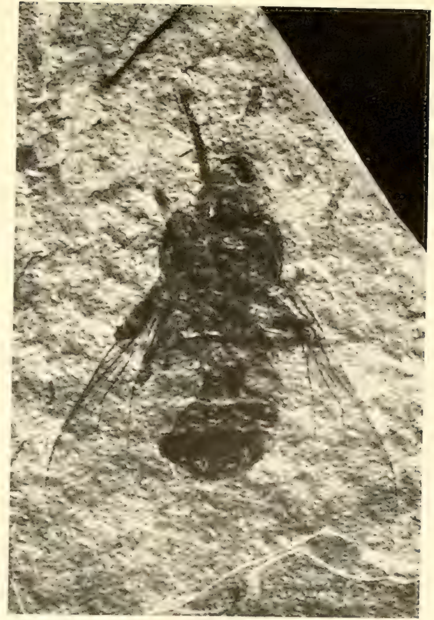
ERAS	PERIODS	ADVANCE IN PLANT LIFE	ADVANCE IN ANIMAL LIFE
PALEOZOIC	Permian	Age of giant club mosses	Extinction of ancient animals and rise of land vertebrates
	Pennsylvanian		Rise of primitive reptiles and insects
	Mississippian		Rise of ancient sharks
	Devonian	Early land plants	Age of fishes and rise of amphibians
	Silurian	Marine plants (seaweeds)	Rise of lung fishes and scorpions
	Ordovician		Higher shelled invertebrates
	Canadian	Primitive marine plants	Rise of cephalopods
	Ozarkian		
	Cambrian		Dominance of trilobites
PROTEROZOIC	Keweenawan	Primitive plants, especially calcareous algae	Primitive animals
	Animikian		
	Huronian		
	Sudburian		
ARCHEOZOIC	Laurentian	Age of unicellular plants	No animal life known
	Grenville		

Ancient crust of the globe (igneous rocks).

The Work of the Paleontologist

How is the paleontologist—the student of fossils, or, as we might properly call him, the historian of the ancient life of the earth—concerned with the larger scientific and technical questions of the day? A generation ago this scientist devoted himself almost entirely to the description of newly discovered species of ancient animals and plants, paying little attention to the nature of the rocks in which he found these treasures. Today, the successful paleontologist must enlarge his interests to include many practical and technical matters. The description of new species, although recognized as essential, has become merely incidental to the pursuit of broader studies.

PLATE 6



Examples of perfect fossil preservation

Fossil leaf from the Miocene shale beds of Baden, Germany. Note the insect gall in the stem

Fossil tsetse fly, a half inch in length, from the Miocene deposits at Florissant, Colorado

It might be well to follow a modern paleontologist into an area hitherto unexplored geologically and see how he determines the ancient history and geological structure of the region:

First, he may make a rapid survey of the area to obtain a general idea of the nature of the underlying rocks and to determine whether they are of igneous or sedimentary origin—in other words, whether they are cooled lavas or sediments laid down in regular beds. Next, he observes the present position of the stratified rocks. Are the layers horizontal, just as they were when first deposited? Or have they been folded and broken by great forces, and so raised above the level of the sea, in many areas into high mountains? We will assume that we are in an area where the rocks lie horizontal. This being true, the paleontologist, or to give him his longer but more accurate title, the stratigraphic geologist, selects a place where the strata are exposed to view, such as a hillside or stream gorge. He then prepares a sketch of the section showing the layers in their regular order and indicating the kinds of rock, the thickness of the layers, and the nature of their contained fossils. Specimens of the fossils are collected from every stratum in this section and carefully labeled as to their original location, so that later, when they are studied in the laboratory, the names of the species may be inserted in the description of the section. Similar sections are mapped out in other parts of the region. Finally, these sections are correlated; that is, they are compared with one another, in order to include in the study all the rocks which outcrop in the area and to learn their order of deposition.

If rock layers in widely separated regions bear the same kinds of fossils, it is evident that they were deposited at the same time. The fossils in any one stratum thus give us information concerning the approximate time of its deposition as well as the forms and habits of the plants or animals then living. From the nature of the rocks

inclosing these plant and animal remains the ancient environment of the living organisms may be inferred. Thus, by studying both the fossils and the rocks, we may reconstruct a picture of the past. Such a section as the one just discussed gives the record of a very small part of the earth's history, but by correlating and combining many sections in various parts of the world it has been possible to compile the geological column (see Inset, page 8).

In areas where the rocks are strongly folded and the crests of the upper folds have been worn away, the upturned edges of the strata outcrop at the surface, revealing the oldest rocks, which ordinarily would be buried underneath the later deposits. In such circumstances the geological history extending over a long period may be studied in a small area. Along the Potomac River, from Washington to Cumberland, Maryland, the rocks are folded to such an extent as to expose every foot of the strata from near the beginning of the Proterozoic era to well toward the end of the Paleozoic, when the great Appalachian coal beds were formed. Another method of studying the older rock formations is by deep drilling; this method enables the geologist to determine the subsurface structure of the earth's crust.

The character of the fossils it contains reveals not only the age of a rock formation but also the conditions under which it was laid down. Sea animals and the muds which buried their remains were certainly not deposited on the land areas of ancient times; so when a rock layer thins out to a feather edge it may safely be assumed that an ancient shore line has been reached. In this way, fossils serve to indicate old land and water areas. By working out such a shore line over a wide area the relative positions of the land and water at that particular period, in other words, the geography of the period, may be outlined. This ancient geography has been given the name *paleogeography*.

Although paleogeographic maps can not show the details shown by modern maps, they are accurate enough to be of great service to the geologist in his search for mineral deposits. For example, certain phosphates were deposited along the old seashore; valuable salt deposits were formed by the evaporation of ancient lagoons; and bog iron ores, as the name implies, were produced in the bogs of former times. There are many other mineral deposits whose location might be determined from a knowledge of paleogeography—a knowledge to be gained only by the study of fossils.

Many valuable deposits, on the other hand, particularly of metallic minerals, occur in igneous rocks in which no fossils are found. The origin, or genesis, of the ore body is an important problem involved in the exploitation of such deposits, and its solution necessitates a determination of the geological age of the rocks inclosing the ores. The clue to this is found in the fossils contained in the sedimentary rocks nearest to such deposits; so that even here the services of a paleontologist are required.

Finally, the petroleum industry has called on the paleontologist for a divining rod of infallible precision and accuracy. Petroleum, according to the most generally accepted theory, results from the decomposition of animal or plant remains deposited under water in sediments of mud. This destructive distillation of organic matter, in order to produce crude oil, must proceed at a moderate temperature and with the aid of certain bacteria. Moreover, the oil when formed must be deposited in a suitable reservoir—such as a porous bed surrounded by impervious layers of rock—and must be near enough to the surface to be recovered without putting too much capital into the sinking of the well. It is no easy task for the geologist or prospector, seeking to locate a new oil field, to find all these necessary conditions fulfilled. Es-

pecially difficult is it to discover a natural reservoir of the required conformation which is at a workable depth.

Much unsuccessful drilling has resulted from neglecting to determine the rock structure of an area. While wells sunk without such geological data occasionally produce oil or gas, more often only a dry hole results from much labor. It is now known that reservoirs of oil are usually formed by upfolds, or anticlines, in the rocks. The first problem, therefore, in the selection of a site to drill is to locate one of these anticlines. The strata may outcrop at various places, and if the rocks are folded the nature of the folds can be determined by observing the dip or angle at which the layers emerge at the surface. But usually the problem is more complicated, and a so-called structural contour map is prepared (Fig. 2). In making this map, a single rock layer containing such fossils and composed of such rock material as can be recognized without question wherever it outcrops, is selected as a "datum plane" for observation. Then by carefully traversing the area the exact altitude at which this layer either outcrops, or would outcrop if exposed, is determined at as many places as possible. If the strata of the region are horizontal, the layer will, of course, outcrop at exactly the same altitude throughout the area; but if the altitude of outcrop varies from place to place it is proof that the layer bends up and down. By means of such determinations it is quite simple to locate the anticlines and to select a place for drilling.

It is evident that fossils are the all-important guides in following the contour of a selected layer and that, therefore, they form the basis for accurate work in the preparation of a structural contour map. In regions underlain by the same kind of rock, such as limestone or sandstone, the different strata usually look much alike; and thus it often happens that a thin individual layer can be recognized with certainty only from its contained fossils, or by its

position in a succession of layers each characterized by distinctive fossils.

It should be noted that the fossils of a given stratum serve only to identify the age and structure of that stratum and do not in themselves indicate the occurrence

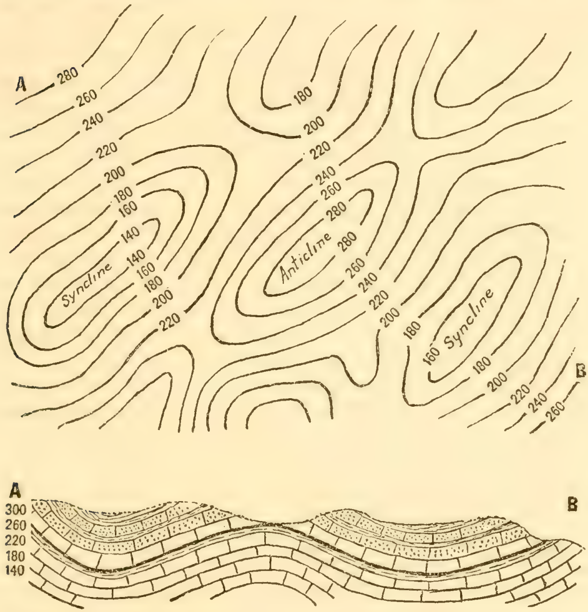


FIG. 2. Structural contour map of a hypothetical area and a geological cross section of the same area

of petroleum. In certain cases, indeed, fossils indicate the *absence* of oil, for petroleum has never been found in the oldest Paleozoic and still older strata; so whenever fossils peculiar to these periods occur, drilling would be useless.

The drill churns the rocks through which it bores into

tiny fragments, which are brought to the surface by suction and constitute a log, or record, of all the different strata penetrated. By means of the fossils in this "core," the paleontologist determines through what particular geological formations the drill has passed. He is thus able to work out the underground structure of the region and to predict just where the oil zone will be found. He needs only three wells to locate an oil structure or anticline provided that in the central one a particular stratum shows at a greater altitude than in the wells on either side.

Unfortunately, drilling grinds up not only the rocks but the contained fossils as well, which are thus rendered for the most part unrecognizable. Certain groups of fossils, however, because of their microscopic size, escape destruction; and these furnish the paleontologist with the necessary information. The best-known microfossils are the Foraminifera (Plate 7, lower), but several other groups need only more extended study to become equally valuable in oil geology.

The use of the Foraminifera is one of the outstanding examples of the application of pure science to the field of economics. These single-celled, usually microscopic animals may be distinguished from other Protozoa by a calcareous covering which each tiny organism either secretes from its own body or constructs by cementing together an outer layer of foreign material, such as sand grains. Because of their regularity of form and the beauty of their surface markings, the Foraminifera have long been studied, though by a comparatively small group of workers. Their stony shells form a large proportion of the material today covering the ocean floor at moderate depths. So abundant are these minute animals in the shoal waters of certain Pacific coral islands that they often impede navigation.

That Foraminifera were equally abundant in past ages is shown by the fact that the great pyramids of Egypt

were originally covered by a layer of limestone blocks of foraminiferal origin. The fossil forms that have proved to be of economic value in the petroleum industry are those found abundantly in the Tertiary and Cretaceous strata. These shells, because of their minuteness, escape destruction in the drilling process, which, as noted above, crushes larger fossils and renders them unrecognizable.

The microfossils are picked out of the crushed rock samples with the aid of a lens, mounted on slides, and studied under a microscope in order that the species may be identified and listed. Comparison of the species occurring in a certain stratum with these lists makes it possible to recognize that stratum. By plotting the depths at which a particular stratum shows in each of the wells, the geologist can determine the undulations of the rock formations and thus locate the reservoirs where oil may occur. By this method it is possible to locate sites for additional wells with greater certainty. On the other hand Foraminifera serve as a check in determining the age and depth of the oil-bearing stratum and thus help to decide the all-important question of whether or not to continue drilling. Again, these fossils serve to determine underground-water horizons, which sometimes must be cased off in order to prevent the oil-producing zone from being flooded.

Foraminifera are found in greatest abundance in the Mesozoic and Cenozoic rocks; they are comparatively rare in Paleozoic deposits. These fossils are at present considered the best guides in oil geology, because they have been more thoroughly studied than other fossils and our knowledge of them is, therefore, detailed and accurate. There is another group of microscopic fossils, however, often found in great numbers in oil drillings, that possess the advantage of occurring in stratified rocks of all kinds and ages from early geological times to the present. These are the Ostracoda, minute Crustacea related to our crabs

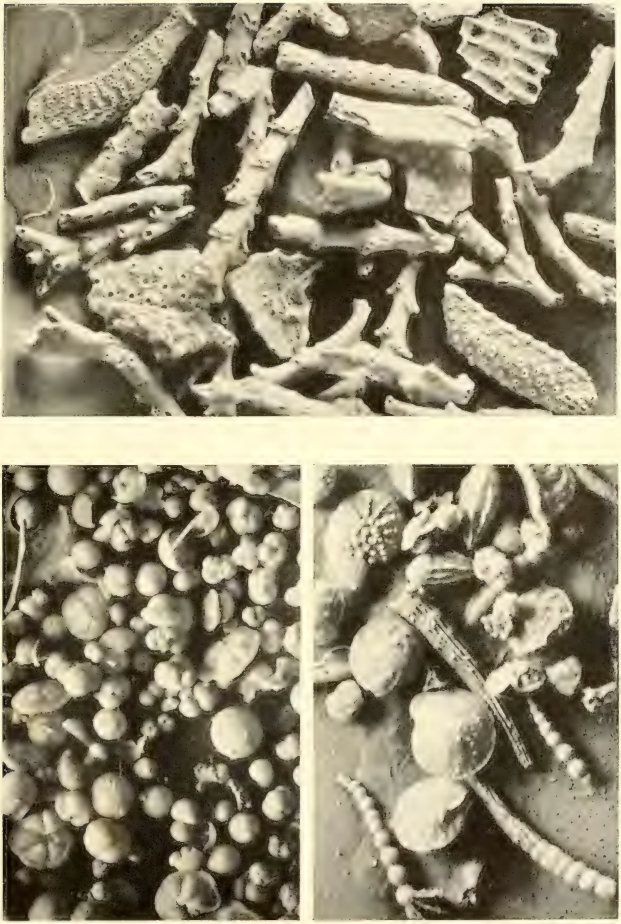
and lobsters but differing from them in being able to secrete a bivalve shell for their protection. If the various species of the Ostracoda differed only in their internal anatomy they would be of no use to the geologist, who finds only their external skeletons or bivalve shells preserved. Fortunately, the surface of these shells is often highly decorated with nodes and spines or other markings, by means of which it is possible to identify the species. This is illustrated in the accompanying photograph (Plate 8), showing specimens of ostracods taken from rocks of different ages. Column A shows six distinct species, illustrating the simple types found only in the oldest deposits. Very distinct ornamentation much more advanced in structure is seen on the three species in column B, which come from rocks deposited during a later period of the earth's history. Finally, the very ornate examples in column C, derived from rocks of comparatively recent age, show how the ornamentation of the shell progresses with the evolution of these tiny animals.

Besides occurring in many more strata, Ostracoda possess another advantage over Foraminifera in being found not only in deposits laid down in the sea but in freshwater beds as well. Moreover, they are frequently found in wind-blown sand deposits, due to the drying up of ancient bodies of fresh water and the scattering of their sediments by the wind.

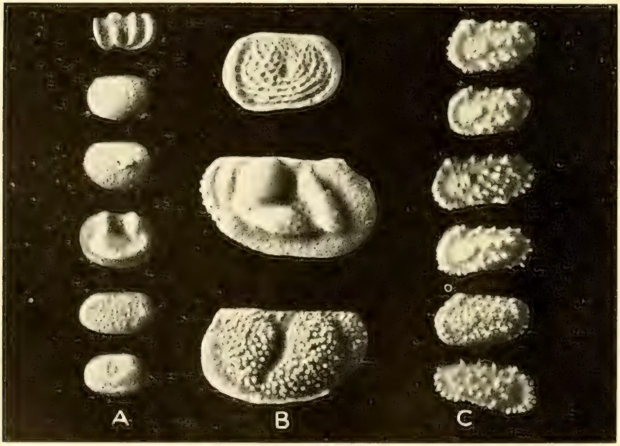
The Ostracoda of certain parts of the geological column have received very careful study; but thousands of feet of strata, particularly in areas where many oil pools have been located, contain species about which, unfortunately, little has been published.

Another group of animals most useful in the oil industry because of their microscopic size have the paradoxical name of "moss animals," or Bryozoa, because they often grow in mosslike colonies. These animals are extremely abundant at all latitudes in the present-day seas and, as shown by fossil remains in the rocks, have been equally

PLATE 7



Microscopic fossil aids to the oil industry
Upper: Fossil Bryozoa brought up in drilling an oil well in Alabama.
Lower left: Modern Foraminifera. Lower right: Fossil Foraminifera.
Enlarged twelve times



Fossil conodonts and Ostracoda
Upper: Slab of bituminous shale, showing how conodonts occur. Lower: Fossil Ostracoda of (A) early Paleozoic, (B) late Paleozoic, and (C) Cenozoic age, showing change in surface ornamentation. Enlarged twenty times

common and widespread since early geological time. The colonies may attain a width of several feet, while individual animals are usually but half a millimeter or even less in diameter. The Bryozoa resemble microscopic corals, but their internal anatomy belongs to a much higher type of structure. Like the corals, they secrete a protecting outer skeleton, usually of calcium carbonate, the outer wall of each individual animal being often marked by the most delicate and sometimes bizarre patterns. With slight variations due to youth and old age, all the animals of the same colony—as indeed all colonies of the same species—are marked by the same pattern, so that a few cells are sufficient to identify the species. After death the brittle colony of calcareous Bryozoa is almost always broken up by the waves and ocean currents into many small bits and so scattered that the sediments in the bottom of the sea are often filled with their fragments. This breaking up and scattering has happened innumerable times in the past, so that layer after layer of the ancient rocks is crowded with fragmentary Bryozoa, such as are shown in the upper half of Plate 7. The process of drilling for oil breaks up these fragments into still smaller pieces, but even so they are large enough for accurate identification.

Certain types of rock, such as shale and sandstone, were deposited under conditions unfavorable to the growth of delicate organisms like the Bryozoa and Foraminifera. In these rocks, however, the paleontologist is fortunate in finding other microscopic fossils, particularly the minute toothlike objects called conodonts. The piece of black shale illustrated in the upper half of Plate 8, enlarged twenty diameters or, in other words, 400 times its natural size, contains several conodonts which, notwithstanding their microscopic size (usually a millimeter or less in diameter), closely resemble sharks' teeth. Sharks were abundant in ancient times, although their teeth—the only bony parts they developed—are all that is now left of them

as fossils. Sharks' teeth, however, are usually large, and so are broken up in drilling; but the remains of their supposed relatives, the conodonts, escaped this fate because of their minuteness. The conodonts are found only in Paleozoic rocks, but here they occur in such numbers as to make up entire strata. An individual tooth usually consists of a basal portion or bar, which was probably affixed to the fleshy jaw and from which numerous denticles of various shapes project; and the size, shape, and arrangement of both the bar and its denticles vary in the different species, while holding true to pattern for the same species. The conodonts are so uniquely marked that it is possible to make exact identifications of them over wide areas of country. Moreover, they occur frequently in oil-bearing bituminous shales, in which most other fossils are lacking. These shales are so similar that without the conodonts it has been found impossible to determine their different ages. Unfortunately, scientists have only begun the study of conodonts, and much research will be necessary before the fullest economic results can be obtained from their use.

The Incompleteness of the Fossil Record

We have called the paleontologist the historian of ancient life. Although the history he has hitherto compiled is far from perfect, yet considering the difficulties of the task, the wonder is that we should have even this incomplete story of the far-distant past. So perishable for the most part are living organisms that fossils, even in their greatest perfection, represent, as a rule, merely shells or bones. Only under very favorable conditions may the softer parts of plants and animals or their imprints be preserved in the rock strata.

Another reason for the incompleteness of the fossil record is due to the enormous changes through which many of the earth's strata have passed since they were laid down as sediments. The metamorphism caused by

compression and uplift has so altered the character of certain rocks that all record of fossil remains has been completely erased from them. The greatly folded and cleaved schists and volcanic tufas of the Piedmont area, just east of the Appalachian Mountains, were long the despair of both geologists and paleontologists owing to the destruction of the contained fossils wherever the cleavage cut across the strata. Only where the cleavage has followed the lines of stratification has the search for fossils in this section been rewarded.

Many difficulties have been overcome by modern methods of study and preparation of material. Specimens are sometimes found almost hidden beneath a coating of hard clay, which can be dissolved off with caustic potash. A single slab prepared in this manner for exhibition in the National Museum revealed on the surface alone over one hundred fossil species.

Nature herself has in many instances been very kind in preparing fossils for us. The water passing over the few feet of Middle Devonian limestone at the Falls of the Ohio has leached out more than seven hundred species represented by innumerable specimens of exquisitely preserved fossils. From freshly quarried limestone we may be able to crack out two dozen species of poorly preserved material; while in a neighboring field, where the limestone has been dissolved and its contained fossils silicified, we find an abundance of beautiful forms which need no further preparation.

Strata which under ordinary circumstances yield very poor fossils can, if silicification has commenced, be made to afford excellent specimens. By exposure to the weather for a year or so the silicification can be advanced to such a stage that etching with acid frees the fossils. The beautifully etched material from the Lower Devonian formation of New York offers an excellent example of this style of preparatory work. Most of the Cambrian and Ordovician formations of the Appalachian Valley yield

shells which, in their original state in the limestone, are almost impossible to use as objects of study; but when changed to silica by surface waters, all the details of each shell are revealed.

Thin microscopic sections are indispensable for identifying small fragments as well as for studying the finer details of certain fossils. Of the many other methods of preparation and study there is one which has proved of inestimable value. This is the whitening process—the use of a coating of ammonium chloride or aniline chloride on fossils that they may be more readily photographed and also to facilitate the study of poor material whose structure may not be apparent. A fossil specimen indistinctly outlined in its rock bed flashes into bold relief when covered with the ivory-white film of ammonium chloride. Casts and molds of fossils ordinarily too indistinct to show the structure will reveal many details when so whitened. Such methods of preparation and study make available a vast amount of material which once seemed too imperfect to be of value in determining the fossil record.

The correct interpretation of the geological record depends chiefly on recognition of the gaps, or missing periods, in the stratigraphic column. For the past twenty-five years the number of these recognized gaps has been increasing; but the intercalation of newly discovered formations has filled in some of the longer breaks. In the past decade the known thickness of the Paleozoic rocks has been almost doubled by such additions; and beneath the Potsdam sandstone, once considered the oldest fossil-bearing sedimentary rock, many thousands of feet of highly fossiliferous Paleozoic strata have been brought to light.

As such discoveries are constantly being made, it is probably but a question of time until a fairly complete fossil record may be established. A break at one point will be bridged over by a formation from another area which will prove to be the missing one; until it may be

that only in a few regions, such as on the borders of the continents, will any gaps remain. We shall continue to trace faunas from one area to another, until in time we shall know their complete geological history. While the earliest records must always remain imperfect, our knowledge of the floras and faunas of later times will suffice for all practical purposes.

CHAPTER III

OCEANS AND CONTINENTS

In any description of the very peculiar Dead Sea, one of the first facts stressed is that its surface lies 1,292 feet below the level of the Mediterranean. No description of any spot on the earth's surface is complete unless the altitude above or below sea level is stated. Sea level is so commonly used as a point of reference that no thought is given to the possibility of its variation. It is assumed that the relative positions of the land and sea at any point remain the same year after year, and that the strand line has occupied the same position for long ages except for local modifications due to filling or cutting or the shifting of the beach sand by the waves and currents.

Many things prove conclusively, however, that the height of the land surfaces above sea level does not remain stationary, but that changes in altitude are continually going on. For instance, on the coast of Italy, near Naples, stand the ruins of a Roman temple. At present the floor of these ruins is exactly at the water level, so that the waves wash all the way across it. This shows how the sea has encroached upon the temple since the days when it was first built. Moreover, we find, ten feet or so above the present sea level, in columns still erect, borings made by a marine animal that can work only beneath the permanent water surface, which proves that the temple was at one time much more deeply submerged than it is at present. As it is most probable that the site of the temple was originally well above the reach of the waves, we may safely infer that several changes have taken place in the

level of the land at this point since the Romans built the structure.

To be sure, this region is near the great volcano, Vesuvius, and for that reason may be regarded as particularly unstable; but beaches raised above the present reach of the waves, drowned forests, and other phenomena indicative of varying sea level are in evidence at many places along shores far removed from any volcano. The United States Coast and Geodetic Survey has recently resurveyed a section of the California coast and revealed a change in altitude at one place of more than twenty feet since the previous survey. Here, at least, is a nonvolcanic portion of the earth's crust that is not stable at the present time.

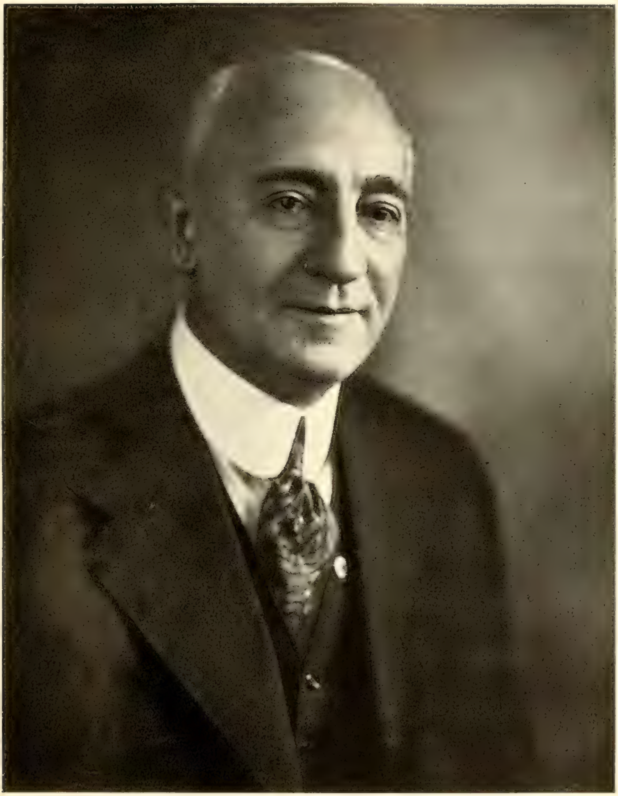
In school, when we were taught that an ocean or a lake is "a body of water surrounded by land," we thought of the ocean or lake as a mere surface. But to get the proper conception of such a body of water we must regard it as an immense basin or depression more or less completely filled with water. Therefore, if we could drain the oceans of today and then stand on the sea floor, these dry basins would appear as great plains, while the continental portions of the earth's surface would stand up as elevated platforms and their edges would look like high mountains.

The average depth of the ocean basins is over twelve thousand feet, or about two and a half miles, and except for widely separated ridges their floors are so flat that if they were drained the eye could detect little departure from a perfectly smooth plain. At present the oceans are slightly overfull, as a result of which a strip around the edges of the continental platforms, varying in width in different localities, is flooded by the waters. We speak of the waters covering this strip as "epicontinental seas"; that is, "seas on the continents." Off the coast of California and of western South America, the sea-covered continental shelf is often but a few feet wide. At many places in the eastern United States, on the other hand,

the edge of the continental platform (disregarding such indentations in the coast line as Chesapeake Bay) is located several hundred miles out in the ocean. In western Europe the edge of the continent is far out, and the epicontinental sea is so shallow that a relatively slight lowering of the present sea level would again practically drain the North and Baltic seas and reunite the British Isles with the main continental mass of Europe.

Remembering that the strand line of today shows many evidences of oscillation and that at many places we now have extensive seas on the continental platforms, it is not a great step for the imagination to picture times when much more of the continents were under water than at present. We have, for example, in Hudson Bay a broad expanse of land flooded by a shallow sea. This condition was brought about by a depression of the North American continent. If a further depression of the continent should take place—a depression sufficient to double the present depth below sea level of the floor of Hudson Bay—these waters would spread southward through the Lake Winnipeg region and up the valley of the Red River to a point beyond Fargo, North Dakota, on the west, while on the east they would join the enlarged Gulf of St. Lawrence and an enlarged New York Bay, submerging a great part of Canada and New York State and converting both New England and the Province of Quebec into islands.

If this supposed depression should affect the entire continent equally, the Gulf of Mexico would extend northward (as it has in the geological past), covering the Mississippi Valley and ultimately joining the enlarged Hudson Bay in the basin of the present Great Lakes. Such extensive flooding of the North American continent has happened repeatedly, but only in the manner to be described presently. This subsidence and flooding must not by any means be regarded as a breaking up of the continental mass but as merely a relative sinking of parts of it, allowing the already existing epicontinental seas to



Edward O. Ulrich, Associate in Paleontology of the National Museum, who originated important principles of stratigraphy

flood additional areas but not violating the general rule of "once a continent, always a continent."

When geology began to develop as a science, in the early part of the nineteenth century, all studies of the earth were influenced by the idea that at any given time in the past the same general conditions prevailed in every part of the earth. It was thought, for instance, that when conditions were such in the Rhine Basin as to induce the deposition of the thick beds of coal now there, coal was being formed the world over, and this geologic time division was consequently named the Carboniferous. As explained in a succeeding chapter, this "Carboniferous period" has now been replaced by three distinct periods, known in America as the Mississippian, Pennsylvanian, and Permian. Likewise the period during which the chalk beds of southern England and the adjacent parts of Europe were deposited was regarded as the "chalk age" and named the Cretaceous. Similarly, in thinking of the flooding of the continents or portions of them, it was imagined that the land masses of the whole earth subsided equally and evenly at the same periods, just as we supposed a few moments ago that the land masses of North America might do.

After long-continued studies of the rocks and their contained fossils, however, the geologists were forced to the conclusion that the old idea of uniformity of conditions over the whole earth during any particular period of time was no more true in the long-ago past than it is today. It was only quite recently, and mainly due to the pioneering work of Dr. E. O. Ulrich (Plate 9), that anything approaching a true conception was reached regarding the character of the continental movements which bring about the formation of the epicontinental seas. Our supposed uniform depression of North America, allowing the Arctic waters to extend south from Hudson Bay and mingle with those of a further drowned St. Lawrence River and an enlarged Gulf of Mexico extending up the

Mississippi Valley, never took place in the fashion assumed. One need not go far along a recently uplifted shore line to note that the amount of vertical movement was not everywhere equal. A little more extended observation soon establishes the fact that the land masses shift in an oscillatory fashion; that is, two adjacent areas, whether large or small, play seesaw, as it were, with each other. Hence, for instance, if the land mass around the present Hudson Bay were to subside, it is more than likely that that around the Gulf of Mexico would rise at the same time, bringing with it an area now submerged and thus reducing instead of enlarging the present Gulf. A glance at the map of North America will show that recent earth movements have, on the whole, depressed the northern and elevated the southern part of the continent.

It is in the shallow epicontinental seas that marine life is most abundant today, just as it must have been in the past and for the same reasons: The shallow water permits the penetration of light; the agitation by the waves insures oxygen; and the sediments from the land bring the minerals essential for plant life, which in its turn supplies the necessary food for many kinds of marine animals. Hence in a sea such as Chesapeake Bay a very great abundance of life is to be found. It was also in the epicontinental seas that the sediments derived from the land or the lime from the living organisms accumulated to form the stratified rocks of today, even as sediments are accumulating in the seas today to form the stratified rocks of the future; and it is in these solidified former ocean beds that we now find the shells or skeletons of marine animals entombed and preserved for our study. Thus the fossil remains and physical evidence recorded in the sediments of the seas that flooded portions of the continental platforms in ancient times—first from one direction, then from another—constitute practically the only available record of the great geological past of the earth. Nowhere has any

rock been discovered that represents an uplifted portion of the true deep-sea bottom.

To get these general ideas more clearly in mind, let us review briefly the events of a single geological period—the Cambrian; for more or less regular or rhythmic floodings of the continents mark the beginning and the end of each major subdivision of geological time, so that the study of any one will illustrate the chief phenomena of geological history.

At the beginning of the Cambrian period the North American continent had what might be called its triangular backbone already outlined. On the north there was an upland, the so-called Canadian Shield, which now comprises northeastern North America and is bounded on the south and west by the great chain of rivers and lakes made up of the St. Lawrence River, the Great Lakes, and the lake region of Canada extending northward to the Arctic Ocean. The eastern side of the triangle consisted of a mountain chain parallel to but east of the present Appalachian system. The western side was formed by a chain of mountains just beginning to be uplifted and near the present west coast. The interior of this triangle must have been a broad, rather smooth plateau. In other words, North America was even then a true continent in that it consisted of a large land mass with its edges turned up into mountains.

A long, narrow trough stretched down the eastern side of the continent just inside the eastern highlands, at its greatest extent reaching from northern Greenland to Alabama. Because of the oscillatory character of the earth movements, this trough, like all others, was flooded several times; and each time the waters were again withdrawn, exposing the sediments derived from the mountains to the east. These sediments, on being dumped into the trough, caused further subsidence of the bottom and became the foundation of the present Appalachian mountain system.

During the intervals when this long, narrow epiconti-

nental sea connected with the Arctic Ocean, it was cut off from the Atlantic Ocean and the Gulf of Mexico, but subsequently tilting closed it off in the north and opened it to the south. Another long, narrow trough extended southward from the Arctic, through the region that is now the Rocky Mountains, as far as southern Nevada. Thus, while the major structural features of North America were already outlined, one would scarcely recognize at first sight a map of the continent as it then appeared, with seas replacing the present Appalachian and Rocky Mountains and with other mountain ranges occupying what is now the coast line on the east and west.

As previously stated, the major subdivisions of geologic time are based on periodic floodings of the continents. It seems that the continents are emergent at the beginning of a geological period; that is, they are mainly out of water and standing well above the reach of the sea. Then follows a subsidence, not gradual or even, but in a series of waves; and these increase in extent until frequently considerably more than half of the continental platform may be covered by shallow seas, after which the oceans are repelled through a series of minor uplifts until the land is again emergent.

Consequently in the second (Middle) division of the Cambrian period the seas again formed in North America, following much the same lines as in the Lower Cambrian epoch, but occupying wider areas, particularly in the west. During much of this Middle Cambrian time the sea was absent from the eastern trough.

When Upper Cambrian time arrived, the continent became more restless, and the seas were very greatly extended. For instance, the Pacific was able to send waters into the interior through a gap that opened somewhere in the Puget Sound region, with the result that some of the fossils of western North America are the same as those of China. During the Upper Cambrian epoch the eastern sea became more extensive simply by widening its trough.

For a brief time some movement tilted the continent in such a way that the Arctic waters were withdrawn from the Appalachian trough and a tongue of the Atlantic Ocean was able to extend itself into Alabama, with the result that animals then common in the waters that covered the British Isles and Scandinavia were admitted to the waters then occupying an area which later was uplifted and became the present Appalachian Mountains. And this we know because we now find their fossil remains in beds of soft yellow shale lying between other strata containing fossils of animals from the Arctic Ocean. These land movements and the extensions of arms of the oceans into the interior of the continents explain very clearly why two consecutive rock beds may contain radically different sets of organisms, for evolution has always continued uninterruptedly in each major ocean basin. Since the physical conditions of an ocean do not change quickly, it is not to be expected that the evolution of its life forms would be very rapid; and an epicontinental sea always contains the life of the ocean with which it connects. With continuous but slow evolution going on along individual lines in each ocean, successive incursions from the Arctic Ocean, for example, even though at long intervals, would bring in faunas very much alike; whereas an incursion from the Atlantic, even if simultaneous, would bring in radically different animals. This results in the apparently incongruous intermingling of fossils that we find in the Upper Cambrian of Alabama and does not represent, as is quite generally thought, rapid evolution in embayments far from the parent sea.

The greatest geographical change wrought in the Upper Cambrian was the flooding of great tracts of the interior of North America that apparently had received no sea waters for a long time. Extensive seas covered parts of the Rocky Mountain region and large areas in central Texas, Oklahoma, Missouri, the Black Hills (South Dakota), and Wisconsin. Some of these seas, whose

waters were derived mainly from the Arctic or Pacific oceans, were so shallow that it is now almost impossible to find in their sediments a single shell or trilobite test that the waves have not ground to bits. At many places the shales are ripple-marked and have preserved even the impressions made by the scattering raindrops from a light shower that fell when the muds were laid bare either by wind drift or by the receding waters at low tide. At several places in the Cambrian rocks these very shallow water beds contain numerous pseudomorphs of salt crystals; that is, casts of crystals formed by the evaporation of the sea water. In most areas in our Western States the prevailing sediments are limestones or shaly and siliceous beds with lime lenses and sheets, a situation due to the low relief of adjacent lands. Another striking feature of these strata is the great abundance of "edgewise" beds—thin, platy layers of lime crowded together at all angles. These beds were formed by the drying of mud flats when, as we often see happen today, the mud cracked and a thin surface layer hardened and became loosened by the curling away of its edges from the underlying material. Later, waves of the incoming sea gathered up these dried scales and piled them into the layers of "edgewise" conglomerates.

As the Upper Cambrian epoch drew to a close, its epicontinental seas grew so shallow that many of them could no longer support life; and finally the waters withdrew to the ocean basins. The succeeding cycle of advance and retreat of the seas formed the next geological period.

Two general principles, consequently, have evolved from our stratigraphic studies; namely, that the earth is divisible into ocean basins and continental blocks, both of which have always retained their respective characters, and that all our fossil records are contained in rocks representing sedimentation in epicontinental seas whose extent and position were always due to relative subsidence of limited areas within the continental masses.

CHAPTER IV

THE BEGINNINGS OF LIFE

BEFORE taking up the story of how and when life came into being on the earth, we may profitably consider certain psychological processes that affect the solution of the problems involved and consequently our understanding of geological history. We first note the universal tendency to fix dates for and to measure the time between the major events in earth's history. Moreover, we desire to have this measurement of time expressed in years, the unit of time to which we are accustomed. But such a unit becomes absurdly inadequate when it is applied to geological chronology. Nor is it possible to divide most natural events into clean-cut periods of time, since neither the beginning nor the end of such happenings can be fixed with absolute certainty. For example, we can not say that birth occurs at a given instant, since it actually extends over that variable period of time when the new life exists as a seed, an egg, or an embryo. Neither is death instantaneous. In the normal life of an animal or plant a time comes when the physiological processes are no longer able to replace normal wear, and so death begins. Thus it may be a quarter of a century from the time the fine oak in front of your house begins to die ere the last spark of its life is extinct. How much more difficult, then, must it be to define the beginning and the end of a geological period whose processes have occupied not years but eons!

Also, the human mind requires everything in nature to be classified. Usually this means that we expect to find

an orderly arrangement of the organisms or objects classified, from lower to higher forms. In other words, we very often continue to cherish the Aristotelian concept that we unconsciously held as children or until we began a closer study of nature; namely, the concept of a definite place for each group of individuals in nature, assuming that every individual falls into one or the other of certain groups, the whole forming a series of steps like ordinary stairs. But year by year it becomes increasingly evident that all conceivable classifications are exceedingly imperfect, often entirely erroneous, and far too simple to accommodate the infinite variety of nature's creations. The oft-repeated statement that it is not possible to draw sharp boundaries in nature must ever be kept in mind. Not only can no sharp boundaries be drawn, but a satisfactory classification for many individuals can not be made until our knowledge has been extended far beyond its present scope. By that time it may well be that the facts revealed will have become so numerous and their interrelations so complex that it will tax the greatest minds to devise even the semblance of a classification or system sufficiently comprehensive to be of any use.

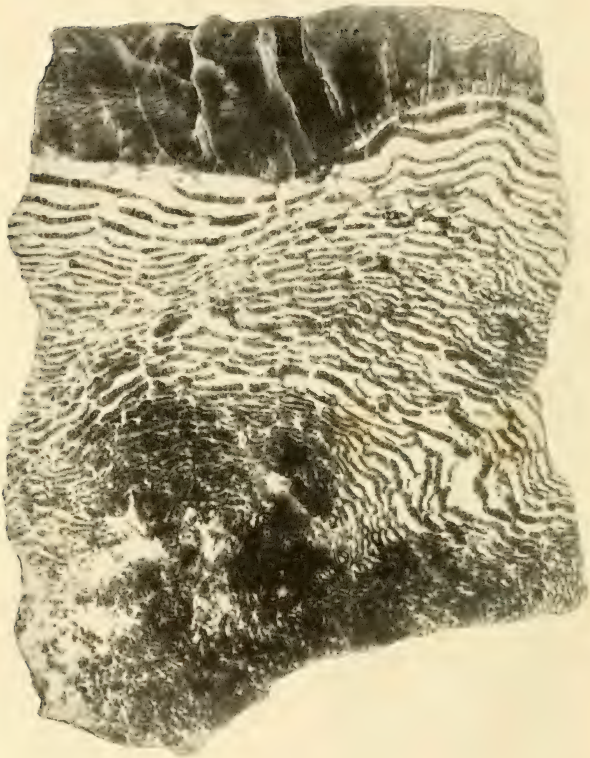
It is true that most of our present classifications show a gradation from the simpler to the more complex. If the underlying principles of these systems approach the truth, there should be some evidence that the earliest plants or animals belonged predominantly to the "lowest" orders and that plants preceded animals on the earth. Let us see if the older rocks contain any such evidence.

The Archeozoic

The earliest forms of life must be looked for in the first rocks known to have been deposited in layers under water; for, as previously explained, only such sedimentary beds can contain fossils. Moreover, when the earliest sediments were being laid down, rains had already fallen and oceans and continents had appeared, thus supplying

PLATE 10

Banded and crumpled limestone beds of Archeozoic age at Silver Peak, Nevada. Crumpling is common in beds of this age. Photograph by Dr. C. D. Walcott



Top layer of a limestone reef of Archeozoic age thought to be of organic origin. If so, the fossil algae that it contains represent the oldest known form of life

the necessary conditions for both land and marine life, whether plant or animal. Therefore, although we find almost no direct evidence of fossils in these oldest sedimentary rocks, it seems probable that the simplest forms must have existed then; accordingly the grand division of geological history marked by the laying down of the first sedimentary rocks is known as the Archeozoic era—the time of the earliest life.

The history of the Archeozoic strata, as it has been worked out by long and patient research, helps to explain the absence of fossils from these rocks. Archeozoic formations, since they constitute the strata upon which all succeeding strata have been deposited, form the backbone of the continents and cover over two million square miles in the northern parts of America and Europe and in central Asia. In North America they outcrop today in three general areas: the first, a great V-shaped area around Hudson Bay known to geologists as the Laurentian Shield; the second, a low plateau just east of the Blue Ridge Mountains of the eastern Appalachians, called the Piedmont Plateau; and the third, the Cordilleran region in the western part of the continent, in which they appear in scattered spots. These exposed Archeozoic strata thus give to North America its roughly triangular shape. That they also underlie a considerable part of the continent is revealed in deep drill holes and in deep stream cuttings. In the Grand Canyon, for example, the Colorado River has cut down through other rocks to the Archeozoic strata, which are now exposed at the present river level.

Seldom, however, do the Archeozoic strata present an ordered succession of layers. Oldest of the stratified rocks, they have been subjected to the various changes that have occurred through the long ages of geological history (Plate 10). Compressed and crushed many times in the great foldings of the earth's crust, they have often lost their definite layer arrangement and have been completely altered to crystalline rocks. Such metamorphosed

beds—at one place in Ontario they attain the enormous thickness of eighteen miles—present a contorted mass of sediments, lavas, and intruded granitic masses so greatly altered by the forces accompanying later earth movements that even their original chemical composition has been completely changed. It is not surprising that such profound alteration should have erased all evidences of life, even had plant and animal remains been originally entombed in these rocks.

The sedimentary origin of the metamorphosed rocks is shown only in those localities which have escaped intense folding—where the Archeozoic beds have kept their original stratified character. It is here alone that we may expect to find evidences of the earliest life on the earth. Although direct evidence that life existed in the Archeozoic is almost entirely lacking, there are enough indirect indications to testify that some of the lower plant forms were fairly abundant even then.

What direct evidence there is of the existence of Archeozoic plants consists of the microscopic structures that appear in thin sections of the least-altered limestones of this era obtainable. These structures resemble the blue-green algae which still grow abundantly and whose fossil remains make up the limestone deposits found in the rocks of all geological ages (Plate 11). About 1860 Sir William Dawson, a noted Canadian geologist, discovered in the provinces of eastern Canada globular masses of rock, several feet in diameter, made up of concentric layers of alternating white and dark-colored material. Because of the resemblance of the microscopic forms that composed these rocks to some of the one-celled animals of today, Dawson believed that they were fossils representing the remains of the primeval form of all animal life, and accordingly named them *Eozoon canadense* (dawn animals of Canada). Many long hours of scientific study have been devoted to *Eozoon*, and volumes have been written to prove the so-called genus either animal or vegetable in

origin; or, as some mineralogists will have it, neither the one nor the other, but purely mineral. The latest researches have led scientists to regard *Eozoon* as either a mineral or else the earliest representative of the blue-green algae already mentioned. If it is indeed a fossil seaweed, then *Eozoon* represents the oldest known form of life.

As indirect evidence of life in the Archeozoic, we have the vast amount of the limestone itself in the rocks of that age. In southern Ontario and the Adirondacks the Archeozoic beds are eighteen miles thick, and nearly ten miles of this thickness was deposited as limestone. Since we now know that algae alone are capable of chemically precipitating lime carbonate, the presence of enormous quantities of limestone in this region, now mainly altered to marble, strengthens the evidence in favor of life in the Archeozoic. Another indirect evidence is the presence of great quantities of graphite disseminated through these same rocks. This fact indicates the burial of plant matter in the sediments, forming coal or coal-like substances; for graphite is derived from coal by metamorphism. Carbon in rocks, therefore, becomes strongly indicative of life existing at the time of their formation.

Summing up the available evidence, we feel sure that life existed on the earth during Archeozoic times and that it consisted, just as we might expect, mainly of lowly forms of plants. None of these extremely ancient rocks offer means of preservation adequate to record the existence of higher plants or animals, and consequently we learn nothing about such forms from them.

As in each of the grand divisions of geological time, the end of the Archeozoic era in North America was marked by the formation of a great mountain system. From Labrador on the north, the mountains of this system extended southward more than a thousand miles to the St. Lawrence River, whence their name, the Laurentian Mountains. In the many millions of years since their formation, active wearing away of the land by stream

cutting and weathering has resulted in the complete disappearance of these ancient highlands. Today all that is left of them is a plain almost at sea level; but the story of the great domes and folds of rocks which once rose high in the air is told by the underlying strata, tipped at all angles.

The Proterozoic

Abundant sediments for the formation of the strata laid down in the Proterozoic era, the grand division of time following the Archeozoic, were furnished through the weathering of the great Laurentian Mountains. Enormous thicknesses of sedimentary rocks were deposited during this era; and, since many of them were not subjected later to such strong mountain-building forces as were most of the Archeozoic rocks, the sequence of events may be read in greater detail in them than in those of the preceding age.

The continental platforms and the deep-ocean basins had been differentiated by the beginning of the Archeozoic era, and it should be borne in mind that in all the great earth movements of succeeding ages no part of the deep-ocean bottom was ever uplifted to form a part of a continent. This we know because no sediments comparable to present day deep-sea deposits have ever been found on the present lands.

Many beds of Proterozoic age favorable to the preservation of fossils contain no evidences of marine animals and plants. This does not mean that the oceans in that era were not populated, but merely that such beds may have been laid down in great fresh-water lakes formed by the gathering of rain water into depressions in the interior of the continent. Because such lakes did not connect with the sea, marine organisms could not have found their way into them; nor could they have existed in their fresh waters.

Proterozoic deposits outcrop in much the same general

areas as do Archeozoic deposits. Three distinct periods have been distinguished for this era, designated, for convenience, as the lower, middle, and upper Proterozoic. In a region extending from Lake Huron far northward into Ontario we find the lower Proterozoic represented by a thick series of sediments—originally coarse, cleanly washed gravels and sands. Overlying these beds is another thick series, representing the middle Proterozoic, which contains more limestones than the lower Proterozoic beds but is chiefly notable for tillites, or consolidated ice deposits. In the region around Lake Superior the middle Proterozoic beds contain the rich iron ores that furnish about eighty-five per cent of our entire supply of this valuable metal. The upper Proterozoic, likewise, is represented in the upper Great Lakes region by several thousand feet of mostly coarse sediments, accompanied by a tremendous outpouring of volcanic materials. The later stages of this period of intense volcanic activity resulted in the concentration of the rich copper, silver, and nickel deposits of the Lake Superior region and Ontario.

The upper Proterozoic is represented in western North America, also, by strata reaching an aggregate thickness of about seven miles. Most of the beds are sandstones and shales, but thick strata of limestone also occur. These beds, best typified by the Belt series, may be seen in the Big Belt and Cabinet ranges in Montana and thence northward into British Columbia. Strata of the same age are exposed in the Grand Canyon, where river cutting has laid bare a tremendous geological section.

Mention has been made of ice deposits in the middle Proterozoic (Huronian) beds north of Lake Superior. Similar deposits occur in the Rocky Mountains and also in northern India, southern Australia, northern Norway, and possibly South Africa. Especially fine exposures are found in the Yangtse Gorges and elsewhere in China. The wide distribution of these deposits, even though most of

them were apparently made by icebergs or floe ice rather than by glaciers, indicates that this was a time of cool climates all over the earth. It is possible that these various tillites do not all represent the same period of time, but rather a series of cold spells. Formerly it was thought that such world-wide distribution of ice deposits gave evidence of an ice age or glacial period induced by a marked change in world climate. Now, however, most students have abandoned the idea of sudden pronounced changes of climate occurring simultaneously over the whole earth and tend to regard the presence of ice in a given area, whether in the form of mountain glaciers or of large sheets, as the result mainly of changed geographic conditions in that area combined with the factors known to determine variations of climate over the earth at the present time. The principal geographic factors affecting world climate as a whole are, of course, the height of the continental masses above sea level, the position occupied by their mountain barriers, and the distribution of land and sea.

So much for the manner in which the Proterozoic rocks were formed and the physical history of the era. What evidences of life do these rocks reveal? As yet, no well-defined forms of animal life have been found as fossils in them; but fossils of blue-green algae, whose occurrence in rocks of the Archeozoic era has been discussed, are abundant (Plate 12, upper). These simplest plant forms belong to the same group as present-day seaweeds, and their resemblance to living species is quite startling. They are called "calcareous" algae because of their habit of secreting lime carbonate.

The blue-green algae of today are continuing their work of building limestone reefs in many streams and lakes. In Green Lake, New York, for instance, one may see a ledge many feet thick that these lowly plants have built all around the shore. In many of the Appalachian streams, wherever a limestone area is drained, we find

large dams of this formation, as, for instance, just west of Harper's Ferry, West Virginia (Plate 12, lower). Other deposits are laid down in spongy masses incrusting twigs, or in onionlike layers about sand grains or pebbles. Of course, we all know of such deposits around warm and hot springs, but few people notice their formation in ordinary streams and lakes. In Montana and other Rocky Mountain States one may often collect algal lime deposits from Proterozoic beds and, in the same vicinity perhaps, find them in three or four younger strata also as well as newly formed ones slowly accumulating in an adjacent spring or stream. Proterozoic algal deposits are of world-wide occurrence; some are associated with the interesting iron deposits of the Hudson Bay region.

The minute structure of the individual plants may sometimes be brought out by polishing the surface of the rock in which they occur. Nature herself frequently does this on a large scale through the action of glaciers, as may be seen in Lester Park, near Saratoga Springs, New York, where a great glacier of a much later period than the algal deposits spread out over the country, scouring off the surface soil and polishing the rock beneath it, then receded, leaving the algal reef exposed.

Further evidence of the great abundance of these simplest forms of plant life at this time in earth's history is shown by the very large and rich iron-ore deposits of the Proterozoic, which indeed gave it the name of the "Great Iron Age." The Proterozoic iron ores from Michigan, Minnesota, and Wisconsin, which supply by far the largest part of the iron used in the United States, were likely deposited originally at the bottom of lakes or seas as rock sediments rich in this metal. Later on ground waters dissolved out the impurities in the rock, leaving behind ores of nearly pure iron oxide. Recent researches have shown that these enormous deposits of iron, no less than those of limestone, resulted from the life processes of bacteria and algae, processes which may be observed dur-

ing summer in many ponds or sluggish small brooks where decaying organic matter is present. Usually the iron oxides first appear on the water as a scum that looks like oil, for which it is frequently mistaken; but its true nature may be determined by sticking a finger through the film: if it is oil, it will cling to the finger; but if iron, it will be brittle and break into irregular fragments. Sometimes many tons of iron ore may be found at the bottom of such pools. Therefore the great beds of apparently sedimentary iron in rocks of the middle Proterozoic furnish as strong an argument as the presence of limestone or carbon for the existence of plant life during that period.

Although no well-defined forms of animal life appear as fossils in rocks of the Proterozoic, there are evidences that animal life did exist in that era. These evidences consist chiefly of sponge spicules and worm tubes and trails. Certain small, obscure forms are thought to represent single-celled Protozoa. Crustacea have also been described from the Proterozoic, but whether the particular fossils so described are really crustaceans is somewhat doubtful. Still, it is probable that such animals actually lived during the Proterozoic era.

Thus, in spite of the scantiness of the evidence in the rocks of the era, we note, in the Proterozoic, some development of life since the Archeozoic. Just how inadequate and incomplete the available record is can be understood only when we come upon a section of strata in which fossils have been well preserved. Such an occurrence is described later on. Because of the incompleteness of the record, our knowledge of the past must represent but a few fragmentary chapters of the whole story.

However, when we are tempted to regard as insignificant the evolutionary progress made during the immensely long Archeozoic and Proterozoic eras, we should remember that in reality this progress was of the most profound significance. During those long ages, the supposed

Ancient and recent algal limestones

Upper: Algal limestone of Proterozoic age, showing characteristic concentric laminae. Lower: Recent algal limestone that formed part of a large dam built by algal growth across a stream near Harpers Ferry, West Virginia

original "primordial protoplasmic globule" performed the almost incredible feat of drawing sufficient sustenance from earth and air to evolve into organisms capable of performing the simpler functions of plant life. These lowly plants in their turn furnished the necessary food supply for the earliest animal forms, which by the end of the Proterozoic had progressed probably as far as the comparatively complex organisms of worms and crustaceans—a tremendous advance from their humble amoebalike ancestor.

CHAPTER V

EARLY PALEOZOIC HISTORY

The third grand division of geologic history, known as the Paleozoic era, or "time of ancient life," opens with North America lifted high above the sea; for the end of the Proterozoic era, like the end of the Archeozoic, had been marked by a period of great mountain building. Again, as in the preceding era, the newly created mountains were gradually worn away by rains and the cutting of streams. The resulting sediments, deposited at the bottom of the Paleozoic seas, entombed the remains of many animals. Today these may be found as fossils in the Paleozoic rocks, each great period of that long era having its characteristic forms.

Thus we find a much fuller record of life during the Paleozoic than during the two preceding eras; and the record becomes more and more complete through succeeding eras, since the younger the strata, as a rule, the less altered or deformed they are. It has been estimated that more than half of the geological time from the laying down of the first sedimentary rocks until today had elapsed by the opening of the Paleozoic era; yet most books on geology, in their discussion of the various strata of the earth's crust, devote far less space to the earlier strata than to the later, because so little can be learned concerning the life of the earlier eras.

Geologists indeed once believed that life began with the first great division of the Paleozoic—the Cambrian period. This made it difficult to explain the sudden appearance, in strata of succeeding ages, of many different

classes of animals. But since, as we now know, the age of the earth is much greater than was formerly thought, and since it has been proved that life did exist in the earlier eras, this appearance of many and varied organisms can not be regarded as so sudden as was once believed. It results merely from the sudden improvement in the completeness of the record.

The Cambrian period takes its name from Cambria, the Roman title for Wales, where fossils of that age were first studied in 1822. Like other periods, the Cambrian is conveniently subdivided into three epochs: Lower, Middle, and Upper. In no one locality do we find in sequence all the beds known to belong to each epoch. Some twenty years after English geologists first studied and named the Cambrian, strata of the same period or system were discovered in Bohemia, where better-preserved fossils were secured. Later still, more complete fossiliferous sequences were found in Scandinavia and in Newfoundland. The best and most complete series, however, occur in the Rocky Mountains and the upper Mississippi Valley, and consequently these two occurrences have become the world's standard in the classification of Cambrian fossils. Our knowledge of these western beds is due almost wholly to the lifelong work of Dr. Charles D. Walcott, late Secretary of the Smithsonian Institution, who through his fundamental researches enlarged our knowledge of the Cambrian deposits until, instead of assigning to it the trifling importance suggested by the few insignificant Welsh beds with their contained fossils, we recognize it as one of the most important of geological systems. In spite of the enormous amount of data accumulated by Doctor Walcott through many years, not until now has it been possible to begin the task of reconstructing a satisfactory comprehensive picture of the life of this period.

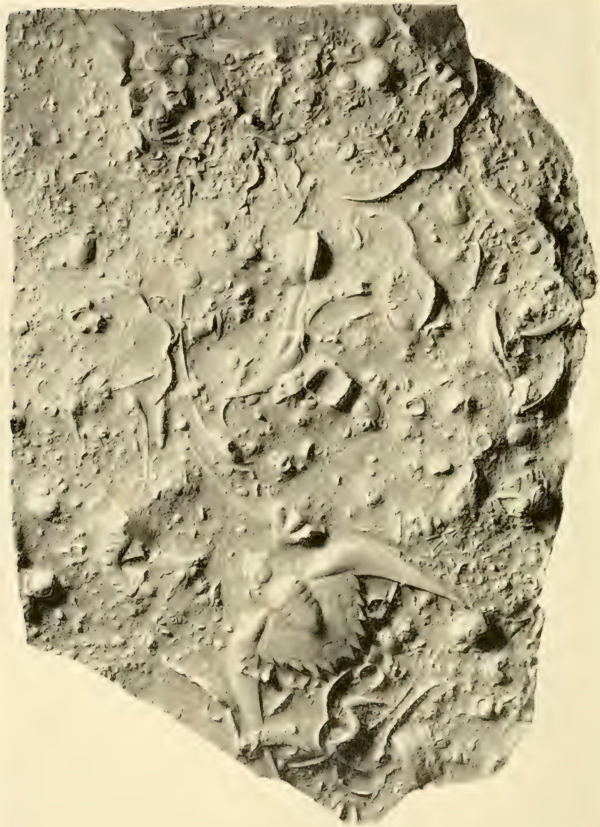
Lower Cambrian strata outcrop in many scattered places in North America, Eurasia, Australia, and possi-

bly Antarctica. In Nevada, the northern Rocky Mountain region, the southern Appalachian region, and elsewhere, beds which in places aggregate over seven thousand feet in an unbroken sequence represent the accumulations of the weathering products washed off the land, together with the lime extracted from the seas by the life processes of certain organisms. Usually, however, few fossils are to be obtained from Lower Cambrian beds except in the upper several hundred feet of the series. Such fossils as do occur are readily grouped into related faunas, for all deposits laid down in embayments or troughs connected with the same ocean naturally contain the fossil remains of the same animals, and these differ only in such degree as local variation causes. By Middle Cambrian time the epicontinental seas had become more extensive than those of the preceding epoch; in western North America, for instance, one arm of the Arctic Ocean extended from Alaska down the Rocky Mountain trough into what is now Arizona; while on the eastern side of the continent another arm occupied a similar long, narrow trough connecting northwestern Greenland, the St. Lawrence Valley, and Alabama.

An exceptionally fine illustration of the relationship of a fauna in any continental sea to the ocean from which it was derived is found in the Middle Cambrian rocks of North America. As has been explained, two epicontinental seas extended southward through North America from the Arctic Ocean during this epoch—one in the west from Alaska to Arizona, and the other in the east from Greenland to Alabama. Consequently the same fossils occur in both the eastern and western parts of the continent wherever Middle Cambrian rocks were laid down in waters derived from the Arctic Ocean. But in southwestern Newfoundland and eastern Massachusetts, separated from the Appalachian trough or sea by only a few miles, the Middle Cambrian beds contain a set of fossils entirely different from the Arctic faunas and identical with

PLATE 13

Northeast face of Mount Robson, British Columbia, showing well-exposed fossiliferous marine strata more than two miles above the present sea level



Cream-colored limestone slab, of Middle Cambrian age, from China, containing many fossils. The Chinese make ornamental caskets from such slabs, and these were the means of bringing the fossils to the attention of European scientists

the faunas of similar beds in Wales, central England, and Scandinavia. Evidently the sediments in these widely separated regions were laid down in seas connecting with the same ocean—in this case, the Atlantic—which must have been separated at that time from the Arctic by some sort of barrier; otherwise, the faunas of these two oceans would not have been so completely differentiated.

Finally, at the beginning of the Upper Cambrian epoch came, as is usual in the latter part of a geologic period, a more widespread submergence of the continents. Thus, for instance, in North America we find the inland seas greatly extended in the western trough but withdrawing early from the eastern. In addition, wide tracts in the interior of the continent were flooded, and the receding waters left fossiliferous strata in Wisconsin and in the Black Hills (South Dakota), the Ozarks (Missouri and Arkansas), the Wichitas (Oklahoma), and the Llano uplift (central Texas). These strata show a much greater proportion of limestone than of any other material, indicating that the lands bordering the epicontinental seas in those regions were comparatively flat and consequently contributed fewer sediments than did the marine organisms.

Since we have learned that deposition of vast quantities of limestone can take place in cold as well as in warm seas, we assume that any geological period that has left no definite evidence to the contrary must have had a climate approximating that of recent time for similar latitudes and elevations. Therefore, as the Cambrian rocks give us no indications to the contrary, we presume the climate of the Cambrian period to have been approximately the same as it is today in the regions where these rocks occur.

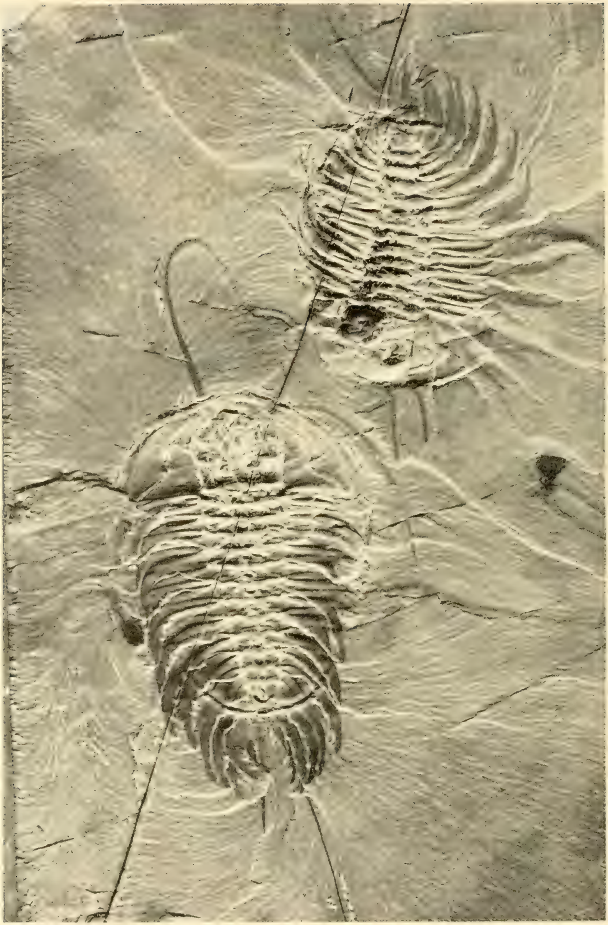
A brief summary of Cambrian life will enable us to see how much progress had been made in that remote period toward evolving the animal and plant forms of the present day. Wherever the base of the Cambrian deposits is visible a great unconformity exists (Plate 15), by which

we mean a want of continuity between the Cambrian deposits and the underlying strata. This may be explained as follows: After the deposition of the youngest Proterozoic beds and before that of the oldest Cambrian strata the continents were uplifted above the reach of any marine waters and hence exposed to erosion. During the long interval before the lands again were submerged—this time by the Cambrian epicontinental seas—much erosion took place, creating an uneven surface over which the Cambrian strata were deposited in the new seas. This uplift and erosion of the Proterozoic strata caused the new set of beds (Cambrian) to lie unconformably on the older; in other words, the two sets could not be parallel if any tilting of the older series had accompanied their uplift, and in the rare instances where the movements did not tilt the under beds the old hills and valleys interrupted the sequence and prevented the younger set of beds from fitting smoothly on top of the older. As previously explained, this profound unconformity indicates the lapse of a long interval of time; consequently we should expect the organisms of the Cambrian period to differ greatly from the earlier ancestral forms, because in the interval between the lifetimes of the two, evolution continued uninterruptedly in the permanent oceans. Another general fact to be kept in mind is the absence of all authentic records indicating the existence during the Cambrian period of either land plants or land animals. However, we have a little indirect evidence that lowly forms of plants may have been living on the land.

The older beds in the Lower Cambrian are mainly clastic, many of them consisting of coarse sediments, with only here and there materials that are suitable for preserving such life as may have existed. Among the oldest forms preserved are animals that we call Archaeocyathinae, a name referring to their great age and cup shape. They occur in limestone, sometimes in the form of reefs that simulate the coral deposits of later periods. It is

PLATE 15

Example of an unconformity. Cambrian quartzites resting on surface of Archean gneiss, east of Melrose, Montana. The gneiss was so long exposed to the weather before the Cambrian period that it has disintegrated to a depth of many feet



Trilobites from the Burgess shale quarry, near Field, British Columbia. These nearly perfect specimens were obtained by Dr. C. D. Walcott. Note the well-preserved feet and antennae

doubtful if these animals, which appear to be primitive corals, could have built the reefs alone; what is more likely is that they were aided, just as are the present-day corals, by bacteria and algae, which cemented together their cups and thus made the reefs. Archaeocyathinae occur in both eastern and western North America, and in Siberia, Sardinia, Australia, and Antarctica. Probably not all the deposits containing them represent the same geological time.

In the highest of the Lower Cambrian beds many kinds of animals are represented by numerous fossils, so that we can take stock of the animal world of that day. Here we find, in addition to the above-described forms, the following: Sponges, which had already appeared in the previous era and now assumed the peculiar forms known as "glass sponges"; jellyfishes and their relatives; worms; brachiopods; several kinds of primitive snails; and an unexpected abundance and variety of crustaceans. Most important among the crustaceans, which represent the highest form of life reached during this period, was the trilobite (Plate 16), destined to become earth's dominant animal type for a long stretch of time. Studying this array of marine animals, we are amazed at the progress made in evolution. Of the higher forms existing today only the vertebrates and certain orders of the Mollusca are lacking among the Lower Cambrian fossils. Some of the lowest forms are also missing from the record, due to the fact that they had developed no hard parts which might resist decay long enough for them to become entombed and fossilized.

As time went on following the Lower Cambrian period the sea invaded still more of North America, until finally the whole of the present Mississippi Valley was engulfed. In this wide area and elsewhere over the globe the trilobite continued to flourish, and under the favorable conditions then existing it began in time to evolve into strange forms. But this tendency to elaborate its originally simple

structure into a complex one evidently marked the end of the trilobite's mastery of the seas, a mastery which was destined to last only during early Paleozoic time. For from that time on we find its descendants becoming weaker and weaker, until at the end of the Paleozoic era this type of animal disappears from the earth never to return.

Trilobites were the first fossils to attract the attention of naturalists, who, at the time of their discovery, had no modern representatives of their tribe with which to compare them and therefore believed them to be fossil caterpillars or butterflies. This ignorance of the true nature of trilobites is reflected in the names given them. One group was called *Paradoxides* or the "paradoxical animal," while another was *Agnostus*, "the unknown one." It remained for Linnaeus to recognize the trilobite's relationship to the shrimps, crabs, and lobsters of today.

Because of the abundance of trilobite remains in the rocks of the Paleozoic era, their curious shapes, and especially their great value in determining the age of the strata in which they occur or in recognizing strata of similar age all over the world, paleontologists have devoted much time to their study. Unfortunately, the features of the animal that are necessary to determine its relationships—the appendages of the body, such as antennae and swimming legs—are very rarely preserved. But one student hit upon an ingenious scheme for tracking down its relationships. Noting its resemblance to the horseshoe crab, an animal frequently washed up on the seashore along the coast of the Atlantic, the observer believed that if the trilobite really was an ancestor of the horseshoe crab a study of the eggs of the latter would reveal the fact. With the aid of the microscope he studied the embryos within the eggs and discovered that their later stages were strikingly like certain trilobites of the earliest Paleozoic rocks. This indicated the relationship between the modern crustaceans and the trilobites, and showed that both are descended from the same primitive stock.

Trilobites in a slab of Trenton limestone. Collected by Dr. C. D. Walcott in the vicinity of Trenton Falls, New York

A view of the Burgess shale quarry, near Field, British Columbia, where Doctor Walcott brought to light the finest specimens of Cambrian fossils known to science

The subject was studied from a different angle by Doctor Walcott, who spent his boyhood days in the vicinity of Trenton Falls, New York, where the trilobites, here occurring in the Trenton limestone, aroused his curiosity and determined his career as a paleontologist and geologist. One of these very slabs of Trenton trilobites collected by him as a boy is shown in Plate 17. Young Walcott read of the problems regarding the trilobite and determined to solve them. It seemed to him that specimens still retaining the antennae and swimming appendages might be found in the solid limestone and that thin sections would reveal at least enough traces to furnish some evidence regarding their nature. After years of collecting and many tedious hours spent in preparing thin sections of the rock so that it might be studied under the microscope, he succeeded in solving the problem of the classification of trilobites.

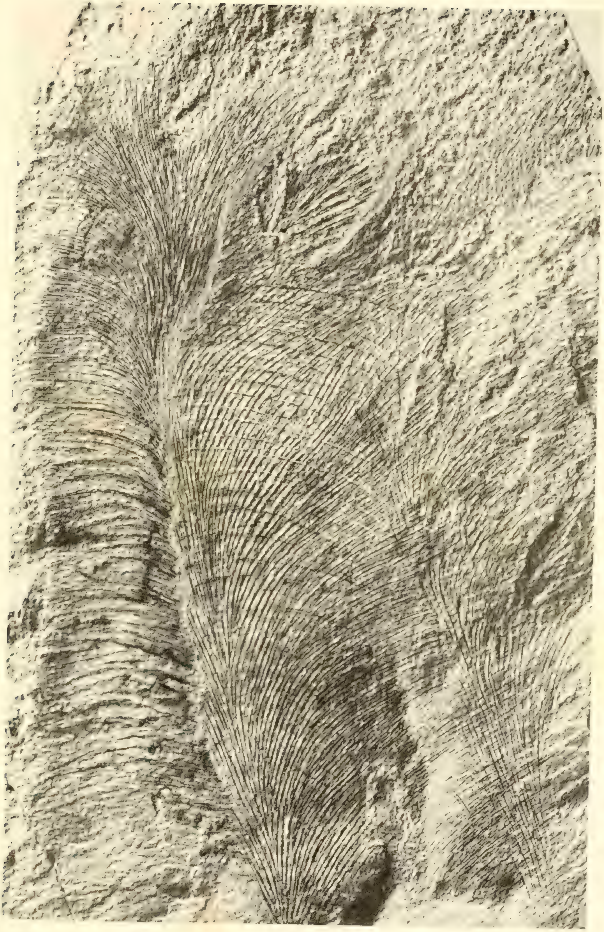
Years later, after Doctor Walcott had risen to be Secretary of the Smithsonian Institution, while examining the rocks along a mountain trail at Burgess Pass, in the Rockies of British Columbia, he happened upon a slab of shale containing a complete trilobite, with all its appendages exquisitely preserved. Had he found such a specimen years before, what time and labor would have been saved! But this discovery only urged him on to look for more specimens. Where there was one there must surely be others, so the next problem was to find the stratum of rock from which this slab had come. It was too late that season, however, to search further, so Doctor Walcott returned the next year (1910) and examined every layer of rock on the mountain side until, finally, he located the source of the slab and the home of the trilobite in strata outcropping on the mountain slope 6,700 feet above sea level. This proved to be such an extraordinary source of fossils that a quarry was opened on the mountain side (Plate 18). The huge chunks of rock blasted out were carefully split into thin fragments, and those containing

fossils—amounting to several tons and constituting the most remarkable single collection of fossils ever yet found —were shipped to the Smithsonian Institution for study. Subsequent seasons yielded hundreds of additional specimens, many of which are still undescribed and therefore unknown to the public. This occurrence, which is so remarkable for the preservation of soft, even jellylike tissues of animals, is confined to a stratum less than fifty feet thick that extends along the exposed rock for only a few hundred feet.

In splitting the hard rock the shale separates in thin layers, so that when fossils are present no further preparation is necessary to bring out their structure. Many layers were crowded not only with trilobite remains but with the remains of numerous other invertebrate animals, among them the delicate lace crab and an elongated shrimplike crab, both so perfectly preserved as to show all their delicate internal structure. Indeed, conditions for preservation at this locality were so perfect that, whereas in other places worms leave traces only of the burrows they make, here the petrified remains of actual worms were found, showing the stomach and other internal organs through their outer covering. The National Museum now possesses over thirtv-five thousand specimens from this locality.

Even a cursory examination of the Burgess shale fauna and flora revolutionized our idea of early life and upset many of our previous conceptions. For not merely one new animal form, but several dozen groups not previously known to have existed at that early date were found; and in addition the Burgess fossils have contributed much to our knowledge of the anatomical structures of forms already known.

In the Burgess shale the algae are represented not merely in lime masses precipitated by their life processes, but the delicate threads of the plants themselves, as well as their colonies, are recorded in the minutest detail.



Large, perfectly preserved sponges from the Burgess shale. These sponges probably grew as more or less vase-shaped stalked forms

PLATE 20

Burgess shale animals as they are supposed to have appeared in life. Crustaceans, worms, and jellyfish moved about in the quiet waters amid seaweeds and branching sponges. By E. Cheverlange, under the direction of C. E. Resser

Some of these colonies formed close tufts, others were slender and branching, but all find their counterparts living in the seas today.

Among the animal forms occurring in the shale we find, also, many sponges; and again it is not merely their scattered spicules, such as occur in older beds, but their entire bodies that are preserved (Plate 19). Elaborately developed jellyfish and sea cucumbers are so well preserved that we may study their internal anatomy almost as easily as if we had the living animals before us. We find, too, a great array of worms. Some are smooth, resembling a thickened earthworm, or, more correctly, certain marine worms of today. In many of these worm specimens the digestive tract can be traced; and the mouth parts are extended just as are those of a bloodworm when it is put on a hook as bait. Other fossil worms in this collection have numerous hairlike feet, and still others have developed large scales. Certain peculiar forms, not yet studied, indicate the existence of animal groups not hitherto known to have occurred so early.

When we consider the Crustacea, which were the animals of the greatest nerve or brain capacity living when the Burgess shale was laid down and which dominated the Cambrian oceans, we are astonished at the number and variety of the forms they had already evolved. Besides trilobites, we find delicate, lacelike crabs; long, narrow crustaceans with many body segments and appendages; others with shell-like carapaces; and still others with wide, shield-shaped, segmented bodies. Some idea regarding the diversity, appearance, and biologic affinities of this group may be gained from the accompanving restorations (Plates 20 and 21).

The Burgess shale fossils are preserved as an exceedingly delicate, black shiny film on the black shale. One must turn the specimens to the light at various angles in order to see all the features which they present. Fine grain and smooth texture are the qualities that enable this shale

to retain the delicate impressions left in it by early organisms, just as fine texture is the quality that enables the Bavarian lithographic limestone to preserve soft animal tissues embedded in it. Fine texture gives, also, to the last-named stone its commercial value in reproducing designs for printed illustrations, for which use it has no equal. Just why so many soft, delicate plants or animals without hard shells should have escaped decay long enough to become buried in the fine Burgess shale mud, which because of its fineness could not have accumulated rapidly, is a more difficult problem. It is usually assumed that the shales were laid down in an embayment where the waters became stagnant a short distance below the surface. Thus when a dead animal—or a living one for that matter—got into this zone, the accumulated toxic substances resulting from partial decay of the dead organic matter present killed the forms still living and acted as a preservative against further decay. Regardless of its manner of origin, geologists are exceedingly grateful for the record contained in the Burgess shale.

Coming east now to the Appalachian Mountains, we find in their early Paleozoic (Cambrian) rocks, trilobites not so well preserved but equally as interesting as those in the Rockies. Historic Harpers Ferry, West Virginia, lying in the gap cut by the Potomac River through the Blue Ridge Mountains, is near the border line between the Paleozoic and the underlying Proterozoic rocks; and the sandstone forming the near-by mountain ridges contains a curious but characteristic trilobite.

Upper Cambrian strata tell us much about the animals of that period but add few new sorts to those already known. Toward the close of the period the snails, which later became much more important, increased in numbers and kinds; and the trilobites continued their evolution, also increasing in number of species.

But before leaving the trilobites let us look at some of

Another restoration of Cambrian life based on the Burgess shale fossils. Note especially the beautiful trilobite and the two very different sponges—one long and flexible, the other globular and spiny. By E. Cheverlange, under the direction of C. E. Resser

A slab of Devonian limestone, now in the National Museum, in which many trilobites are embedded. The uncovering of these fossils without injury to them required much patience and skill

the species which lived in the later Paleozoic periods, when they were not the masters of the seas. Following the Cambrian period we find them still numerous, but undergoing many changes. Some species have become blind, possibly from spending their lives burrowing in mud and therefore no longer needing sight. Others, like the pill-bugs of today, have developed the power of rolling up their bodies, in order, perhaps, to protect their vital parts from attack. In still later geologic time they assume a spinosity of body so decided that most curious forms result (Fig. 3). These spinose forms did not last long; for

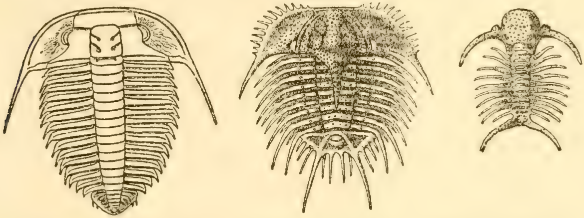


FIG. 3. A Cambrian, an Ordovician, and a Silurian trilobite, illustrating the increase in spinosity as the generations advanced

among the trilobites as among other organisms those species which endured longest were the ones which maintained the greatest simplicity of structure.

Plate 22 gives an idea of the work that the Museum curator puts upon specimens before they are ready for public exhibition. When dug out of the rock of which it formed a part, this twenty-inch slab showed only the tail of a single trilobite upon its surface. By carefully chipping off the surrounding rock with a hammer and small chisel, a whole and perfect animal was exposed. This find led to a search for others in the same slab, with the result that one trilobite after another was uncovered by the chisel, until all those shown in the illustration had appeared on the slab.

CHAPTER VI

LATER PALEOZOIC HISTORY

THE Cambrian was followed by the Ozarkian, Canadian, and Ordovician periods, during which many species of trilobites as well as a great variety of other invertebrates flourished. Much in evidence, also, do we find the ancestors of the snail-like marine mollusk known as the "pearly nautilus," belonging to the class Cephalopoda. This mollusk is perhaps best known from Oliver Wendell Holmes's lines:

> "This is the ship of pearl which, poets feign,
> Sails the unshadowed main."

Today the pearly nautilus has few relatives, but back in Paleozoic times, especially those just following the Cambrian period, its family connection was so numerous and many of the members had such large shells that the nautilus tribe fairly dominated the seas. The coiled shell of the only living form (genus *Nautilus*) is less than six inches in diameter, giving a hypothetical length, uncoiled, of about thirty inches; but the uncoiled shell of the ancestral forms sometimes attained a length of twenty or thirty feet. The pearly nautilus differs from other shellfish in that the shell, instead of remaining a simple cavity, becomes divided by numerous partitions. As the animal grows it moves forward, building about itself an ever enlarging and ever lengthening shell, and at certain intervals shuts off the empty or vacated part by a partition. The nautilus thus occupies only the outermost division of its shell but retains communication with the

rest of it through a tube or siphon which passes through each partition. In the living form the shell is always coiled, but many fossil forms are straight.

In regions where the Ordovician sediments have been covered by those of succeeding ages, the rocks containing the remains of these great shellfish are in many places buried thousands of feet below the surface; but in other regions, elevation of the continent immediately at the close of this period, or the folding of the earth's crust, has brought these strata to the surface, thereby giving the fossil collector an opportunity to unearth the shells. In Canada, New York State, and the Ohio Valley we find a formation (the Trenton limestone) that contains many relics of the ancestors of the pearly nautilus. It is a curious fact that more of these fossil shells are straight than curved, some of the straight forms attaining a length of twenty feet and a diameter of twelve inches. Like the common snail, this Ordovician animal had to carry its shell, or home, on its back. In the course of evolution this protecting cover was changed from a long, narrow, straight shell to one closely coiled and so more easily managed.

Even though the student of fossils usually has only the hard parts of the animal to work with, such as shell or bones, he is able in most cases to reconstruct the animal as it appeared in life. Where there are similar forms living today this is done by comparison; more rarely imprints or outlines of the animal have been left in the rocks and these serve as guides for reconstructions.

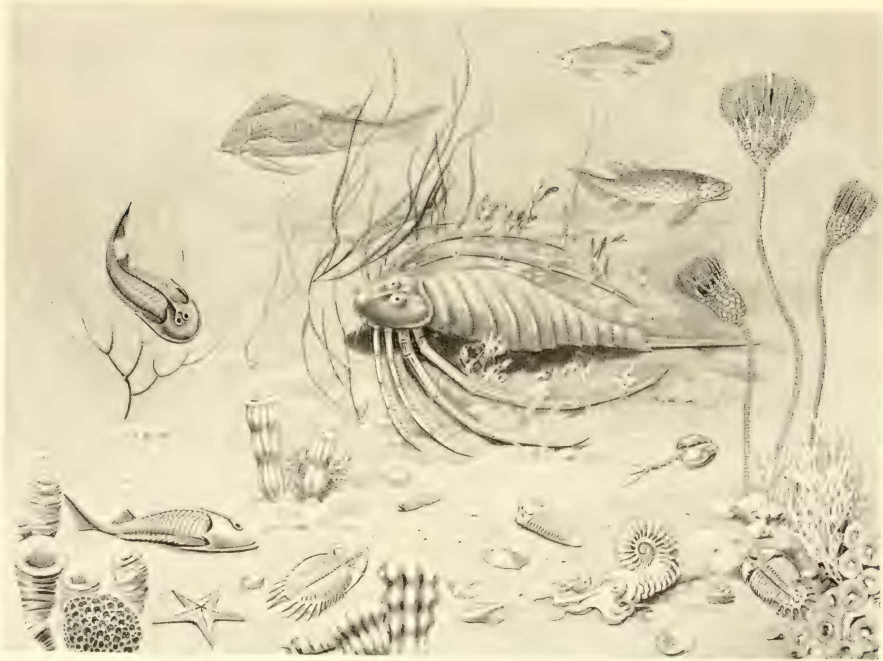
Leaving the Ordovician rocks, with their cephalopods, trilobites, and numerous other forms of invertebrate life, we proceed upward in the geologic column to the Silurian period, the last one in which such life dominated the scene of earth's stage. Here again there is an abundance of sponges, corals, brachiopods, and bryozoans (or moss animals), with the cephalopods still vigorous but the trilobites on the decline. Most interesting among these

Silurian invertebrates—and a form that continued to survive to the end of the Paleozoic era—is the sea scorpion, or eurypterid, a very curious animal distantly related to and not altogether unlike the trilobite. Fossil species of the sea scorpion that measure nine feet in length have been found in Devonian rocks, which represent the geologic period next after the Silurian. A restoration of the animals pictured in Plate 23 indicates clearly that the broad, oarlike appendages served as paddles in swimming or were used for burrowing in the mud. The growth stages of the sea scorpion are well known, larval forms less than two millimeters in length having been found in the Silurian rocks of New York State. These larvae are particularly interesting in that they exhibit the adult characters of the older (Ordovician) forms, thus furnishing one of the many evidences of evolution brought out by fossils. The sea scorpions must have lived in shallow water which was at times entirely drained away, allowing the sun to dry up the sediments and form the familiar characteristic sun cracks. Such sun cracks are common in the Silurian limestones containing the sea scorpions, which gives rise to the belief that the air-breathing or true scorpions of today had their origin in these marine forms.

Continuing our study of Paleozoic life we now come to the strata of the Devonian period. These rocks appear at the surface at many places, but there are few exposures of them east of the Appalachian Mountains. But in the Appalachians themselves, and in the Ohio and Mississippi valleys, outcrops are numerous. At Louisville, Kentucky, a great Devonian coral reef forms the barrier for the falls of the Ohio. Also, at certain summer-resort localities in Michigan, especially at Petoskey, Devonian corals are so abundant that when polished they become an article of commerce and are sold to summer tourists.

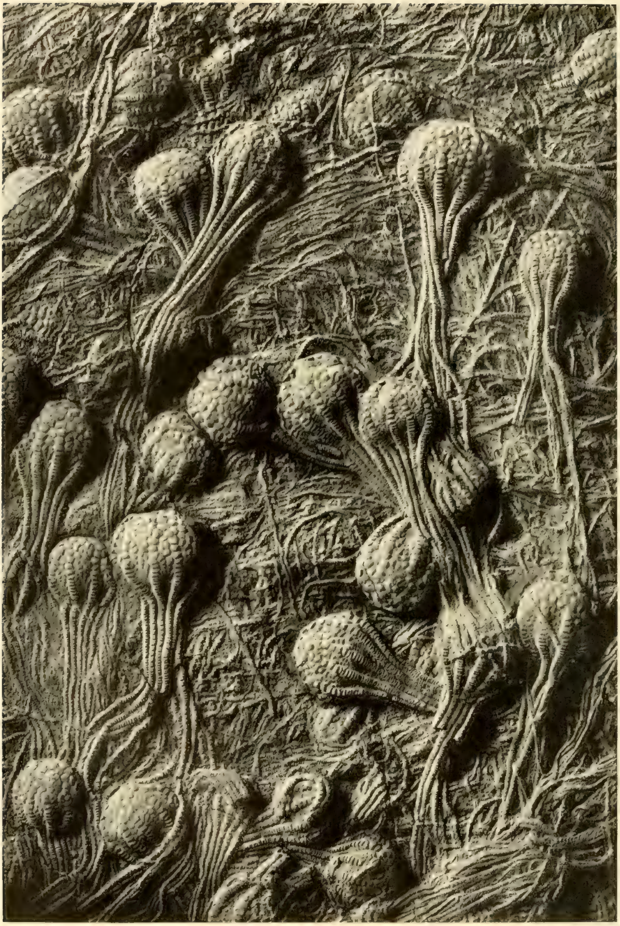
The most interesting and characteristic fossils of the Devonian are the so-called "armored fishes" (Plate 23), the oldest known vertebrates, whose teeth and long bony

PLATE 23



A restoration of the commoner animal forms of the Devonian period. Note especially the spinose trilobites, the giant sea scorpion, and the armored fish. By E. Cheverlange, under the direction of R. S. Bassler

PLATE 24



Fossil crinoids, exquisitely preserved, from the Chalk beds of Kansas

plates appear in the upper strata of this period. The specimens are frequently found in concentric or hardened masses of clay stone, which when split in half show the fossils in great perfection. One genus of these Devonian fishes has been named *Dinichthys*, or the "terrible fish," because of its huge size (twenty feet in length by three in diameter) and the covering of bony plates which incased it as in a coat of armor. Another, with a large, broad, flattened head, is known as *Cephalaspis*. A third is *Pterichthys* or the "winged fish," so named from its two winglike fins resembling the fore flippers of a turtle—a likeness further enhanced by the broad, bony shield which contrasts oddly with the fishlike tail.

Pterichthys was found in the famous Old Red sandstone of Scotland by Hugh Miller, a quarryman whose remarkable scientific insight in recognizing and describing the extraordinary fossils in the rocks quarried by his men won the approval and praise of Louis Agassiz, the greatest naturalist of his time. Miller's classical works, *The Old Red Sandstone* and *Footprints of the Creator*, were the earliest attempts to interest the general public in the subject of fossils. The equivalent of the Old Red sandstone outcrops in New York State and gives rise to the beautiful scenery found at Watkins Glen.

Other Devonian fishes were more graceful in appearance than the turtlelike *Pterichthys*, but they, too, were covered with armored plates. Several orders of fishes, among them the sharks, appeared during this period, but the true bony fishes had not yet developed. All these forms will be found described in Volume 8 of this Series. The fishes of the Devonian are so renowned that this period of geologic time is known as the Age of Fishes.

Geologists formerly grouped together into one system all the Paleozoic strata following the Devonian and styled the geologic time division when they were laid down the "Carboniferous period," because these strata were supposed to contain the world's greatest stores of coal. Now,

however, the American formations included in this "Carboniferous period" are classified as representing three distinct periods of geologic history instead of one: (1) Lower Carboniferous, or Mississippian, so named from the outcrop of beds of that age in the Mississippi Valley; (2) "Coal Measures" proper, or Pennsylvanian, among the formations of which period are included most of the well-developed coal beds of Pennsylvania and others of the Eastern States; and (3) Permian—the most recent period of the Paleozoic era—which derives its name from the Province of Perm, Russia, where beds of its age occur.

The oldest of these strata, the Mississippian, records a period when shallow seas flooded the Mississippi Valley, furnishing ideal conditions for the growth of all the lower forms of marine plants and animals. Many of these, by their life processes, produced limy structures such as we have noted as forming the immense limestone deposits of the preceding periods. Two types especially were abundant in the continental sea: the so-called "sea lilies" (Plate 24), which were not plants, but animals related to the starfish; and the bryozoans, microscopic wormlike creatures whose lacy colonies form a large part of the limestone strata of the period.

Swimming in and out among these lowly forms that attached themselves to the sea bottom, were great numbers of sharks, their presence in the Mississippian seas indicated by their fossil teeth scattered through the strata of this period. Their skeletons have completely disappeared, because they were composed not of bone but of cartilage.

During the Pennsylvanian, or "Great Coal" period, the widespread Mississippian sea withdrew. The level continental floor in the interior of the United States now became warped into a number of shallow troughs and basins, into which the sea repeatedly advanced and retreated, producing an alternation of land and sea. West of Oklahoma the sea oftener prevailed, leaving its record

in deposits of limestone and shale, in which a multitude of marine fossils lie entombed. In the East the retreating waters left a series of ever-changing swamps, dotted here and there with islands rising above the general water level. In these swamps and along the edges of the islands, growing to a height of fifty feet, were dense thickets of jointed, bamboolike plants (*Calamites*), the giant prototypes of the lowly horsetails of today. Further inland, on less boggy soil, grew the scale trees, whose slender trunks, surmounted by a canopy of long leaves, often reached a height of a hundred feet. The scale tree takes its name from its scalelike bark, from which grew long, slender leaves similar to those at the top. These leaves were very unlike present-day foliage, many of them being as narrow as blades of grass. The roots also differed greatly from the roots of modern trees (Plate 25). Instead of digging down into the soil in search of water and mineral salts for nourishment, they spread out over great expanses of surface, forming a sort of pedestal upon which to support the tree on the surface of the boggy soil; for only by this method of growth could the tall trees keep themselves in equilibrium.

Usually only fragments of the bark of these great "Coal Measures" trees are preserved in the rock; but since the arrangement of the scales—sometimes in longitudinal rows and again in ascending spirals—forms a distinguishing character, these fragments are sufficient to identify the various species. Occasionally small trunks or branches are found which, on account of their scaly exterior, are thought by their finders to be petrified snakes. When they are sent to the Museum for identification it is difficult to correct the mistaken idea that they are animal and not plant remains.

Under the scale trees and bamboolike plants of the "Coal Measures" forests grew large species of both the true and the seed-bearing ferns, sheltering in turn more lowly ferns, which flourished in great profusion. Unlike

the trees of the time, the ferns closely resembled the species living today, the main difference being that some of them reproduced by seeds instead of spores. Looking out over a Carboniferous swamp, the only color we should see in the vegetation would be green of various shades, for there were no flowering plants at this time to enliven the monotony with their bright-colored blossoms; and probably the only odors of which we should be aware would be those resinous ones which today pervade our conifer forests.

At times of spore production the whole surface of the swamp was covered with the greenish-yellow dust of liberated spores, which often accumulated in sufficient quantity to make up certain of our present coal beds. Besides the spores, the ribbonlike leaves also were shed each year, falling into the swamp, where the water protected them from decay. Thus the mass of vegetable matter increased yearly and was preserved; and in time the trees themselves died, their trunks adding, literally, more fuel to the coal bed. The fact that coal is of organic rather than inorganic origin may easily be proved. We need only to examine a piece of coal to discover some indications of plant remains; for if it has not been picked clean, fragments of shale attached to it are very apt to show impressions of fern fronds. Again, if we prepare very thin pieces of coal and remove the black material by means of chemicals, we may observe—through the microscope—minute cell structures which are only to be found in plants. And, finally, if we go to the mines it is possible to discover trunks of large trees embedded either in the coal itself or in the rock above or below it. All these facts convince us that coal is of vegetable origin. Plate 26, which shows the conditions in one of the marshy forests of the Pennsylvanian period, illustrates the formation of a coal bed, as well as some of the characteristic plant forms of the time.

The unusual profusion of vegetation existing throughout

Fossil roots and base of trunk of *Lepidodendron*, from the "Coal Measures" of Pennsylvania. The specimen is nine feet across, and the tree in life was probably 100 feet high. The roots spread out to support the tree on the surface of the boggy soil. In the National Museum

PLATE 26

Restoration of a Carboniferous swamp, showing giant club mosses. After Unger

the world during Pennsylvanian times has given rise to the idea that the atmosphere was then more heavily charged with carbon dioxide than it is at present. But numerous insects and other air-breathing animals (to which carbon dioxide in any excessive proportion is fatal) were in existence at that time, as shown by their fossil remains associated with the coal beds. It is more probable, therefore, that a warm, moist climate, similar to that now prevailing in the Tropics, once spread even into the Arctic region and was responsible for the widespread luxuriant plant growth. To climatic conditions has been attributed the fact that the vegetation of the "Coal Measures" forests was remarkably uniform in the two hemispheres. Perhaps more important, however, in producing this universal distribution in "Coal Measures" time of its typical vegetation was the fact that most of the plants of that period reproduced, like the modern fern, by means of spores and that these were easily scattered by the wind.

But, as we have just said, the "Coal Measures" plants were by no means the only organisms living at this time. The low, boggy lands were inhabited by Amphibia—animals which are born and bred in the water and in the early stages of their life cycle have gills like fishes, but which develop lungs on reaching maturity and can then exist out of the water. The development of lungs in animals and of roots in plants marks a very important stage in the progress of both forms of life. Heretofore, as we have seen, life, having originated in the shallow, sunny waters of the epicontinental seas, was necessarily confined to a watery environment. Such forms as were cast, by chance, too high upon the beaches could not survive long after the waters had retreated. All the land above the reach of sea tides or inland waterways was consequently barren, without life of any sort. Now, however, in Pennsylvanian time, plants equipped with roots that could dig into the earth for moisture and animals pro-

vided with lungs to extract oxygen from the air were becoming more and more independent of the water and better fitted for existence on dry land.

The Amphibia of Pennsylvanian times differed considerably from our present frogs and toads. They were huge, salamanderlike creatures with tails, sometimes fifteen feet long altogether. This being the dominant form of life of that period, the Pennsylvanian is sometimes called the Age of Amphibians. These earliest vertebrate airbreathers form a dividing line in the animal kingdom, all forms higher than the Amphibia being equipped at birth with lungs or similar organs.

During the "Coal Measures" there were invertebrate animals, also, that learned to exist out of the water. These were the insects, which were developing in great numbers. We have seen that the oldest known land-living form of animal life is the scorpion—not unlike that of today—which evolved from the great sea scorpions described in preceding pages. Since at the time when they first appeared no other animals had developed air-breathing organs, the sea scorpions (which were carnivorous) had to depend upon marine life for food; accordingly we find them in Silurian times living along the shores of the oceans of that day, probably, as previously stated, in shallow water. In the Pennsylvanian period primitive dragon-flies of huge size, with delicate, lacelike wings, appeared, one found in the "Coal Measures" of Belgium measuring twenty-nine inches across the wings. These dragon-flies, known as Palaeodictyoptera, or "early net-winged insects," led an amphibious life, spending their early or larval stages in the water. Their wings, four in number, were straight and all alike, projecting sidewise like those of modern dragon-flies. Myriopods and primitive spiders now also appeared, and well-preserved remains of them are often found in splitting open the Pennsylvanian shales and clay-iron nodules. Curiously enough, however, the ancestors of the despised cockroaches of

today were then conspicuous among insects both for size and for number of species. In the Pennsylvanian rocks alone, 800 species of cockroaches have been discovered; and although smaller than the dragon-flies they were as a rule comparatively large, some measuring four inches in length. This primitive order of cockroaches, together with the primitive dragon-flies (Plate 27), gave rise through several transitional orders to the modern insects with all their peculiar and complex characters. This evolution was the direct result of drastic climatic changes. The mild, equable, moist climate of the Pennsylvanian changed in the succeeding period, the Permian, to a cold, dry climate, which continued on into the Triassic period of the early Mesozoic era. The insect forms reflected this great climatic change not only by diminishing in size until they were no larger than the modern types, but also by radically altering their mode of development from the egg to the adult. The transformation of the maggot to the fly and of the caterpillar to the butterfly, however, are phenomena of present-day insect life which were developed in times of climatic stress more recent than the "Coal Measures."

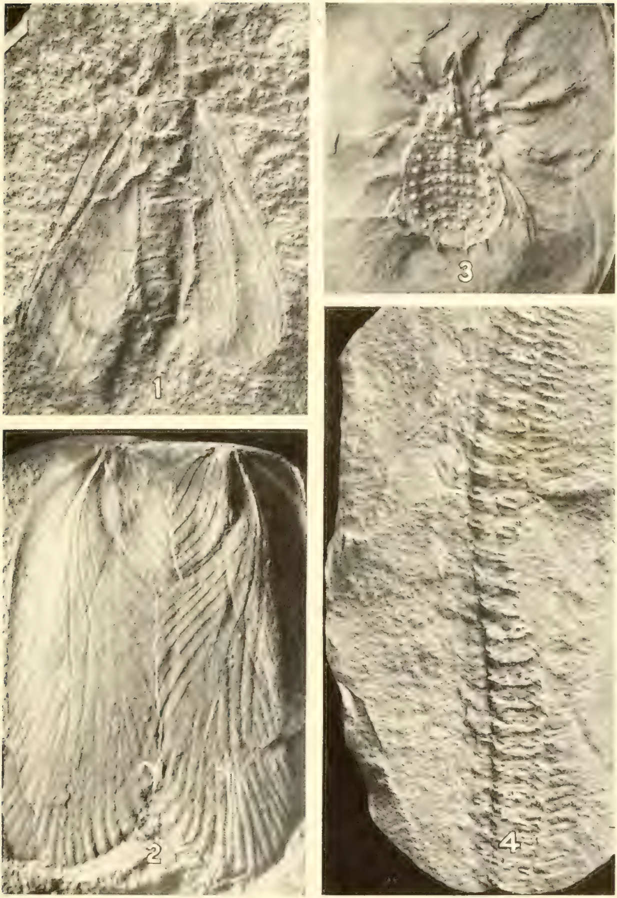
In North America, the land was in a state of unrest throughout the Carboniferous period. As the generations of plants succeeded each other, each adding its substance to the growing coal beds, the great bogs were gradually filled in with decaying matter. With a change of sea level the waters engulfed these regions, bringing heavy mud and sand layers to add their weight to the compression of the beds of vegetation, thus helping to transform them into coal. Following this step the land was again uplifted; and other forests grew upon the old ones now embedded in the rock, thus supplying material for another stratum of coal. Thus the great coal beds of eastern North America were formed, destined to be used by man, who was not even to appear on the earth for

many millions of years and not to discover coal until nearly a million years after his appearance.

The earth had now reached one of its periods of unstable equilibrium. The oscillations during "Coal Measures" time gave warning of what was to come—the final submergence of the land surfaces of eastern North America, followed by their final uplifting; for ever since the close of the Pennsylvanian period the eastern part of our country has remained above water. In this last upheaval the pressure of the Atlantic Ocean upon the shore of the continent, combined with the strain that had been accumulating under the prolonged contraction of the interior and had now reached its breaking point, caused the earth's crust to give way. Huge folds of rock arose with imperceptible slowness into the air and in time, because of the ever-present pressure of the Atlantic on the eastern coast, were compressed together and then overturned to the west. This was the birth of the Appalachian Mountains, which brings us to the last division of the Paleozoic era—the Permian period.

During the Permian the mountain making continued and brought about such elevations of the land and changes of climate that a large part of both the plant and animal life was destroyed. In many parts of the world a period of drought ensued, producing deserts and contributing its share to the great changes under way. With the end of the Appalachian revolution we come to a new order of things in the life of the world. The trilobites have disappeared for all time from the face of the earth, the Devonian fishes and the "Coal Measures" trees have likewise become extinct, while the other types of life have so changed that they are scarcely recognizable. True air-breathing vertebrates now appear, crowding out the once sovereign Amphibia, until these half-and-half creatures pass from the foreground and we find the reptiles ruling in their stead. We now enter upon the era of medieval or Mesozoic life, with which we begin the next chapter.

PLATE 27



Fossil arthropods from rocks of the "Coal Measures" time. 1 and 2, cockroaches, from Illinois; 3, spider, from England; 4, myriapod, or thousand-legs, from Illinois. All these fossils were obtained by splitting open concretions

CHAPTER VII

THE MESOZOIC AND CENOZOIC ERAS

FOLLOWING the "Primary," or Paleozoic, era came the "Secondary" era, and following that the "Tertiary." To the "Secondary" era early geologists gave the name Mesozoic (time of middle life), supposing it to represent the middle or medieval part of the earth's history. The "Tertiary" era they called Cenozoic (time of recent life), because in its strata they found fossils of organisms higher in the scale than those the preceding eras had produced and nearly related to those still living. But while these pioneers were right in their conclusion that the organisms of the Mesozoic form a connecting link between those of the Paleozoic and those of the Cenozoic, they were mistaken in their estimate of the relative duration of these three eras; for we now know that the Mesozoic embraces a geologic time division much longer than that covered by the Cenozoic and that the Paleozoic was longer than the Mesozoic and Cenozoic combined. Hence the Mesozoic is still too recent to be regarded as midway in the geologic scale.

THE MESOZOIC ERA

With the birth of the Appalachian Mountains at the close of the Paleozoic, the seas retreated far from the present continent of North America, leaving vast land areas, very high and in large part desert. Then again the seas gradually rose to fill in the lower-lying lands, but not until the end of the Mesozoic era did they invade the continent to the same extent as they had during certain

parts of the Paleozoic. Meantime new kinds of plants and of animals began to appear, fitted to inhabit the newly formed land areas. Because of the greater variations in temperature and the uncertainty of the food supply, life on the land must always be more strenuous than it is in the sea, where the conditions which affect it are more uniform and equable. The retreat of the seas, therefore, had a disastrous effect upon many of the invertebrate animals which had flourished in the warm Paleozoic waters. Whole groups, such as the trilobites, sea scorpions, and graptolites, were annihilated. Others were so markedly changed that the marine life of the Mesozoic has quite a different aspect from that of the preceding era.

Most conspicuous among the land animals, in number and in size, were the reptiles, particularly the dinosaurs, which have given the Mesozoic its popular name of Age of Reptiles. During that era no less than twenty-five reptilian orders sprang into existence, some of which included the largest land animals that have ever lived. Today but five orders remain; and these, except for the crocodiles and a few snakes, are represented by small and insignificant species only. Since the reptiles, both living and extinct, are discussed in another volume of this Series, they are but briefly mentioned here.

The first part of the Mesozoic era—the Triassic period, so named because exposures of it in Europe indicate that it comprised three well-defined epochs—witnessed a tremendous increase in plant growth. In eastern North America pines and cycads—plants related to the sago palm—ferns and rushes lined the shores of the lakes; and in the West the trees of the celebrated Fossil Forest were growing. Many large trees were washed by storms down the steep slopes of the mountains to the arid plains below and there buried under red sands and clays which had likewise been brought down from the highland areas. Later on water, bearing silica in solution, seeped through

the sands and slowly replaced the decaying wood of the trees with mineral matter, in time completely changing them to stone. Scattered fragments of logs petrified in this way are found over hundreds of square miles in Arizona; in Apache County alone, within an area of forty square miles, there are three "forests," containing thousands of such silicified trees. One of the fossil logs in the Petrified Forest National Monument, measuring 111 feet in length and 4 feet in diameter at the base, spans a little ravine and thus forms a unique natural bridge (Plate 28). The wood of these trees has been changed to hard agate, or chalcedony, which when polished shows a variety of vivid colors ranging from yellow, through red, to purple. Most of these trees belong to the pinelike species *Araucarioxylon*, whose descendants no longer live in the Northern Hemisphere.

During the Jurassic period, the next division of the Mesozoic, forms of life on the land remained practically the same as in the Triassic. Turtles, lizards, and dinosaurs continued to roam the forests. Flying reptiles enjoyed a more varied insect diet than did their ancestors; for besides dragon-flies and cockroaches (descended from primitive Carboniferous insects) they pursued also the newly evolved locusts, ants, and beetles. Birds, except for the reptilelike *Archaeopteryx*, were as yet unknown. Animal life swarmed the seas, the mollusks, represented by the ammonites and primitive squids (belemnites), predominating among the invertebrates and the swimming reptiles among the vertebrates.

The ammonites were so named by the ancients because of their fancied resemblance to the horns of Jupiter-Ammon, under which appellation the chief of the classic gods was represented as having horns like those of a ram. They were cephalopods related to the pearly nautilus and were the characteristic form of marine life throughout the Mesozoic. At the end of that era they disappeared for all time, leaving only their beautiful coiled shells as

reminders of their former existence. More than 6,000 species of these shells have been discovered, some only an inch or two in diameter and others, as shown in Plate 29, measuring as much as eight feet across. If the shell of the largest species could be uncoiled it would have a total length of thirty-five feet. Aside from serving the geologist as an excellent guide to the age of the strata in which they occur, ammonite shells furnish an example of evolution in the development of the septa—the transverse plates which divide the shell into compartments or chambers. In Paleozoic types the partition is simple and more or less concave, but in the Mesozoic species each septum becomes more or less fluted as it approaches the junction with the outer shell. In fragments of this outer shell, the edge of the septum shows as a suture line, the increasing complexity of which in succeeding geologic periods illustrates the evolution of the group.

The belemnites, another group of cephalopods that flourished in the Jurassic period, were ancestors of the present-day cuttlefish or squid. The belemnite's shell was originally external, like the ammonite's, but became internal as the animal grew around and finally surrounded it. The part usually preserved as a fossil resembles a dart; and indeed the Greeks applied the name *belemnos* (a dart) to these shells, believing them to be the thunderbolts of Zeus.

From the belemnites arose the squids which, because of their superior alertness in pursuing other sea creatures, are sometimes called the "pirates of the deep." This title may refer also to their habit of flying a black flag—the famous ink screen behind which the marauder makes good his escape. The ink of the squid is prized as the chief ingredient of the artist's sepia. Fossil remains of the Jurassic ancestors of our modern cuttlefish still show the ink sac containing sepia (Plate 30), often so well preserved that it may be used for writing.

The close of the Jurassic was marked by the birth of

An agatized log bridge in the Petrified Forest, Arizona. The wood has been changed to hard agate and chalcedony

A restoration of the animal forms common in the Jurassic period. Note especially the giant ammonite, the belemnite, and the horseshoe crab. By E. Cheverlange, after R. S. Bassler

the Sierra Nevada Mountains; and this event inaugurated another period known as the Lower Cretaceous, when a new distribution of sea and land areas took place, with accompanying changes in plant and animal forms. A long strait between westernmost California and the Sierras extended as far north as Alaska. In its northern and southern portions great thicknesses of sandstone and shale were deposited, while in the central part were swamp lands whose plants became compressed into coal beds. Swamp lands occurred, also, northeast of the Sierras; the sea covered the region to the south. In these western swamps, during the Lower Cretaceous period, appeared the earliest forms of flowering plants. Ferns, although still abundant, as shown by their impressions in the rocks, no longer reached the dignity of trees, but stood only two or three feet high.

At this time the Age of Reptiles was at its height. Everywhere reptiles dominated—on land, on sea, and in the air. Dinosaurs, crocodiles, and snakes flourished in the swamp lands; enormous turtles and serpents ruled the seas; great flying lizards with a wing spread of twenty feet or more flapped heavily overhead. Fortunately for the yet unborn human race, none of these monsters boasted a brain capacity of more than a few ounces. Having no power to adapt themselves to changing conditions, most of them were doomed to swift extinction. Meanwhile fishes were pursuing a slow but steady evolution into the modern bony types, with nothing to fear from the great ocean floods which during the next and closing period of the Mesozoic were to come rushing in to overwhelm the creatures of the land.

This phenomenal inundation during Upper Cretaceous time submerged the central part of the North American continent from Alaska to the Gulf of Mexico. On low-lying swamps bordering the newly formed inland sea grew ferns and other plants whose carbonized remains were to be transformed into the present coal beds of the Rocky Mountain region. The sea itself swarmed with life.

Chalk beds formed at this time are largely made up of the calcareous outer covering of one-celled plants and animals, which must have existed in countless numbers. Mollusks were represented by oysters and the many-chambered ammonites. Those strange creatures, the "sea lilies," were much in evidence. A specimen of the largest of these crinoids, *Uintacrinus*, is shown on a chalk slab of this period on exhibition in the National Museum. Its arms are four feet in length, and when outstretched gave it an expanse of eight feet. The most characteristic forms of the Mesozoic, the great land reptiles, have been preserved in the muds and sands deposited in the waters that annihilated them. These deposits now form the great Badlands (South Dakota), the happy digging ground of the paleontologist in search of fossil remains of the reptilian monsters of the past.

At the close of the Mesozoic era the sea was completely drained from the land. Mountain building now began at a great rate and continued into the next era. The end of the Upper Cretaceous period saw the birth of the Rocky Mountains in North America and of the Andes in South America. Changes in climate and environment which accompanied this uplift proved fatal to the more highly specialized animals and plants of the Mesozoic, and whole groups of them perished.

The Cenozoic Era

The uplifting of the Rocky Mountains at the close of the Mesozoic ushered in a new era of geologic time—in North America an era of profound change both in the physical aspect of the continent and in the development of its plant and animal life. This era is the Cenozoic, which merges by certain definite stages into our own time.

Like the Mesozoic, the Cenozoic era comprises several distinct periods. The first of these, the Eocene ("dawn of recent life") found the continent of North America

again lifted high above the seas. The Eocene plateaus did not long remain desert wastes; for the grasses that had first appeared in the Mesozoic now spread everywhere and soon transformed the barren highlands into vast green prairies. And following the grasses came a new class of animals—the mammals, destined to dominate the earth and to cause the Cenozoic to be known as the Age of Mammals. The true birds, also, now made their appearance, replacing the lizardlike *Archaeopteryx* of the Mesozoic.

Among plants equally sweeping changes were taking place. The strange cone bearers and cycads of the Mesozoic were followed by flowering plants, which now assumed supremacy. The fossils of the Cenozoic include such familiar trees as the birch, beech, and holly, and many other plants which live today.

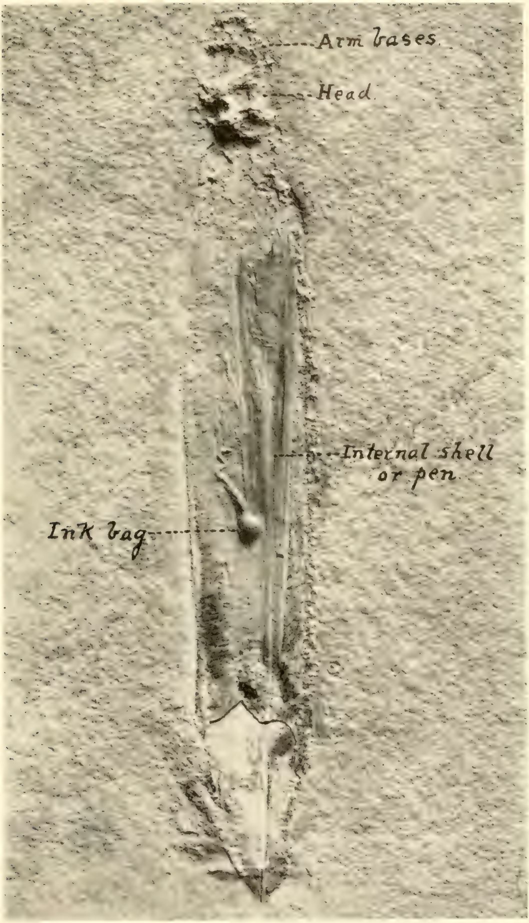
The climate of the Eocene was on the whole exceedingly warm, and conditions remained equable during the following period, the Oligocene ("little of recent life"). In these early periods of the Cenozoic the ocean had again begun to invade the low-lying margins of the continent. In the warm waters of the epicontinental seas marine life flourished in great abundance. Localities in the Atlantic and Gulf States where Cenozoic deposits now outcrop make classic areas for the student of paleontology. Present-day rivers that have kept their courses across recently uplifted Cenozoic strata often reveal rich beds of fossils. A view photographed on the James River, Virginia (Plate 31), illustrates such an occurrence.

The next period, the Miocene ("modern species in the minority"), was an age of great mountain building, during which the Alps and the Himalayas were uplifted. In the Rocky Mountain region of North America active volcanoes overwhelmed and buried in their ashes great numbers of creatures which today are found as fossils in Miocene deposits. A lake at Florissant, Colorado, surrounded by volcanoes spurting out volumes of ashes,

became the tomb of many plants and animals. The ashes, completely filling in the lake, buried more than 1,000 species of insects, besides many species of fishes, birds, and smaller animals, and at least 250 species of plants, preserving them in great perfection. Among the insects we find giant water bugs, many species of ants, bees, and beetles, and several species of the tsetse fly that now live only in the Old World. The plants of the Florissant deposits include trees related to the modern elm, walnut, poplar, and chestnut, and also great redwoods, figs, and magnolias, indicating that the climate of the Rocky Mountain region was milder and more moist during the mid-Cenozoic time than it is today.

In other parts of the world, particularly in the Baltic region, insects and other organisms were preserved as fossils in quite a different manner. Cone-bearing trees which grew in these regions exuded a sticky gum, which on coming in contact with small objects, such as seeds and insects, enveloped and completely inclosed them. In course of time this gum or resin hardened into amber, preserving the most delicate insects as perfectly as if alive.

Immense deposits laid down in the Miocene period consist almost entirely of the remains of minute plants known as diatoms. So tiny are these one-celled algae that they can be studied only under the highest power of the microscope. By thus magnifying them it is possible to see the details of the siliceous coverings they secrete. These little boxes of pure silica are found to be ornamented and sculptured with such complex and exquisite designs that their beauty alone suffices to make diatoms fascinating objects of study. More than six thousand species of these microscopic plants have been described, and the intricate designs of their silica cases figured. The miracle is that all this beauty has been lavished on objects so minute that it takes forty million individuals to make up a single cubic inch of diatomaceous earth, by which



A fossil squid of the Jurassic period, from the lithographic limestone of Bavaria. The ink bag is perfectly preserved

View on the James River, Virginia, showing the fossil shells that line its shores. These are in Tertiary strata, which the river has cut through

name these siliceous remains are known and in which form the diatoms have supplied man with an important economic product. Diatomaceous earth is the chief ingredient in polishing powders used to clean and beautify such valuables as silverware and teeth. It is also used in the preparation of the substance known as "fish food." Geologically its greatest value, perhaps, is as a source of oil, for in deposits of diatomaceous earth occur the richest oil wells. When we consider that a single living diatom may contain a quantity of oil amounting to only five per cent of its bulk, it seems incredible that wells spouting many thousands of gallons a day could have been derived from this source. Yet it is generally conceded that diatoms have contributed in large part to the accumulation of petroleum in certain oil fields. In California much of the petroleum is derived from thick beds of diatomaceous earth folded and faulted in such positions that the oil can accumulate in definite pools. Remembering that in these vast deposits, covering many thousands of square miles and sometimes hundreds of feet thick each cubic inch contains no less than forty million diatoms, we may conceive the possibility of enormous accumulations of oil in them even at the rate of only five or six drops to each diatom.

During the Pliocene period ("modern species in the majority"), which followed the mountain building and volcanic activity of the Miocene, a further drop in temperature produced a climate much the same as we have at present in the temperate zones. Then came the coldest period the earth has known, the Pleistocene ("mostly modern species"), which is the last division of geologic time before our own and which just precedes and merges into the present. During this period the climate so changed that an ice sheet 4,000 feet thick in places, covered most of northwestern Europe and North America as far south as the Missouri and Ohio rivers, an expanse which included some eight million square miles. Evidences of

this glacial period—the Great Ice Age—are still to be seen in the ice caps at the poles, and it may be that we ourselves are living in its closing stages.

The effect of the vast ice sheet of the Pleistocene period was more disastrous to plants than to animals; for the animals migrated ever farther south, while the plants, unless the ice moved very slowly, were inevitably destroyed. Fortunately—so indomitable is the ability of life to persist in spite of adverse circumstances—it needed only the retreat of the ice sheet to enable plants and animals to spread and perpetuate themselves throughout the lands that had been laid waste by the glaciers.

Man himself is supposed to have appeared in North America shortly after the Glacial period, although this is a subject much disputed. However that may be, it is certain that man, by reason of his spreading civilization, has become one of the chief forces of destruction on the earth and is responsible for the extermination of many forms of plant and animal life, as well as for the depletion of vast natural resources.

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Part II

CRUSTACEANS

By

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PREFACE

It is not now nor will it ever be given to one man to observe all the things recounted in the following pages. Though some of the information is drawn from personal experience both in the field and laboratory, I am indebted for a very great deal to other students of Crustacea.

I am especially beholden to Dr. Mary J. Rathbun, dean of American carcinologists; to the Rev. T. R. R. Stebbing; to Dr. W. T. Calman, of the British Museum; and to the editors and authors of the several sections on Crustacea in the recent German *Handbuch der Zoologie.* I have also drawn freely upon a host of authors of less comprehensive accounts—carcinologists and others—for information and direct quotation: some of these are mentioned in the text or credited with such of their illustrations as have been reproduced.

Further, I beg to make grateful acknowledgment to Mrs. Isabel M. Lewis, of the U. S. Naval Observatory, for references enabling me to run down much constellation lore; to Mr. Watson Boyes, of the Oriental Institute of the University of Chicago, for historical information relating to the Crustacea known to the ancients; to the United States Bureau of Fisheries, the Carnegie Institution, the Smithsonian Institution and the Walter Rathbone Bacon Scholarship, and the National Museum for laboratory facilities and opportunities to undertake expeditions which have enabled me to learn much of these fascinating animals at first hand.

And, last but not least, I wish to express my thanks to the Editor-in-Chief and his most able and indefatigable assistant, Mr. John R. Ellingston; to M. Elie Cheverlange, the artist; and to Mr. Henry A. Singer, whose friendly cooperation made possible the luminous plate, and whose thorough understanding of the art of printing is reflected in the volumes of this series.

Waldo L. Schmitt.

Fig 1

PLATE 32

Luminous crustaceans: *Acanthephyra debilis* and *Meganyctiphanes norvegica* (the smaller shrimps). Both occur in the North Atlantic. By E. Cheverlange

This color reproduction has been made luminous to show the effect of the luminescence of these animals, which may be observed in a darkened room by following these simple directions—

1. Be sure the room will be in total darkness when all lights are extinguished.
2. Expose both sides of the picture alternatingly to a strong electric light for two minutes. To obtain the best results, it is advisable to accustom the eyes to the darkness by keeping them closed during this period of exposure.
3. Extinguish the light and the luminescence will now appear much as under natural conditions.
4. Repeat this operation. The colors and luminescence will be more distinct the second time.

CHAPTER I

CRUSTACEANS IN ECONOMY AND HISTORY

My first thought in undertaking this work is, How little man knows of crustaceans, of their significance in the economy of nature as a whole and to himself in particular! Most of us have some personal knowledge of their value as food, but few are aware of the many other ways in which they disserve or serve mankind. Crustaceans may be serious pests: some cause the destruction of crops; others, in oriental and tropical countries, are widespread carriers of disease; ships must be on guard against certain of them or lose in the race for speed and expedition of valuable cargoes; if unmolested, boring Crustacea will destroy expensive wharves and harbor works of wood, undermine sea walls and even bore into stone dock facings, and some go so far as to put submarine cables out of commission. The variety of their habitats is even more startling and less well known. They inhabit most of the waters on the earth—both salt and fresh—the icy waters of the polar regions, the hot waters of thermal springs, the waters of high mountains and those of the ocean's great abysses. Some live in little plant-formed pockets of water high in the tops of trees; others live in rock; and a multitude are parasites, living in and on practically all other classes of animals.

But even an acquaintance with these random facts about crustaceans leaves us still ignorant of their vital zoological importance. Vast hordes of certain kinds are at the base of the "pyramid" of aquatic life. Remove them, and most of the other aquatic creatures will perish,

for crustaceans are the main food animals of the waters. Certain species subsist to a larger extent than any other animals on the microscopic vegetable life of the sea—diatoms. Transmuting this relatively inaccessible food supply into their own minute forms of life, these species in turn become the food of many fishes and other animals. The world's largest living animals, the blue whales—which may measure a hundred feet in length and weigh a hundred tons—as well as the tiny, transparent fish fry—so small that one could hold a hundred in one hand—depend chiefly upon small crustaceans for their food supply. To play so large a part in zoological economy the crustaceans must exist in unbelievable numbers. In fact, there are so many that at times they color the sea as far as the eye can reach.

Creatures of such unsuspected importance and numbers stir our imagination and invite us to find out more about them. But let us beware of lightly following our curiosity in this matter. The attempt to obtain a clear-cut definition of the class Crustacea has left many a student bewildered and dissatisfied. The crustaceans are too numerous, too complex, too remote in their characteristics from the animals with which we are more instinctively familiar for us to form a concept of them which will remain as distinct in our minds as the concept of mammals is from that of birds.

All mammals secrete milk with which they nourish their young, and all birds have feathers; but crustaceans do not seem to have any single unifying character; that is, no character which is common to all the members of the class and which would single out every member from the members of all other classes of animals. The name Crustacea, derived from the Latin word for shell, would imply that the animals so christened are shelled creatures. The crabs, shrimps, and crayfishes—the members of this class most familiar to us—have shells of a kind, of course;

but many other members in perfectly good standing have not.

In a general way we might describe crustaceans as the water-breathing "insects" of the sea. The two classes—Insecta and Crustacea—are related, probably descendants of a common ancestor; and they belong in the same major division of the animal kingdom, the Arthropoda—animals with jointed feet. But such a description could accomplish nothing toward enabling the casual observer to recognize a crustacean on sight, especially if he met one, as he is very apt to do, on land.

In the absence, then, of anything more explicit and helpful, our definition must resort to such negative and alternative characters as—to quote T. R. R. Stebbing—"that the division of the Arthropoda called Crustacea have a segmented body and limbs at some stage of life; that either they have gills or else they breathe in water through their skins; that they have no proper neck; that they never have wings; and that they are born in locomotive freedom. Like insects, they have an integument composed of a substance called chitine. This may be extremely flexible, or, passing through various degrees of tough and brittle, may, by the copious addition of chalky material, attain the hardness of bone or brick."

We can see at once that these various affirmations and negations apply to crab, shrimp, and lobster. They apply also to barnacles, which, though they are generally met with in permanent attachment to ships' bottoms, pilings, or rocks, are born with the ability to move about freely. They apply also to some of those aquatic animals commonly called water-fleas, fish-lice, scuds, and hermits. Of the animals met with in our cellars and gardens, they apply to the wood lice, including sow-bugs and pill-bugs.

The foregoing comprise a very few—the best known—of the twenty thousand odd kinds or species of animals which our definition brings under the heading Crustacea. Man has no popular name for the vast remainder. They

make no direct appeal to his pleasure or convenience, and they live their lives beyond the realm of his physical experience; hence he ignores them.

Man's acquaintance with the few members of the class that he does recognize, however, goes far back—indefinitely farther than the beginnings of written history. Early man—perhaps the Babylonians sometime about

FIG. 4. The constellation Cancer, with the crab *Potamon* as visualized in the sky by the Babylonians

2100 B.C.—translated the crab to the heavens, putting it in the zodiac as the sign of the constellation *Cancer*, which is the Latin word for crab. On every map of the northern hemisphere of sufficient scale is noted the "Tropic of Cancer": Tropic, from the Greek for the turn or change which marks the most northern limit on the earth's surface

Crustaceans on ancient coins and gem stones. 1–4, and 6, coins of Akragas, Kos, and Phaistos; 4, Hercules with the crab underfoot; 6, Gorgon's head on carapace of a crab; 5, and 7–10, gem stones; 5 portrays Cupid in a chariot drawn by two lobsters. From various authors

at which the sun may be directly overhead and at which the sun seems to pause before retracing its course to the south; and Cancer from our "crab" constellation. It is when entering this constellation that the sun is said to be at its summer solstice, i.e., the point in the ecliptic at which the sun is farthest from the equator, in northern latitudes. It is called the "dark" constellation and is supposed to represent the powers of darkness. A little clay tablet dating back to 500 B.C., dug up in the valley of the Euphrates, gives us an unmistakable clue to the crab the Babylonians had in mind. Graven on the tablet in cuneiform characters is the statement that the crab appears as the constellation of the fourth month, under the name of *Nagar-assura*. *Nagar-assura* means the "workman-of-the-river-bed," a description as accurate as it is poetic of the genus *Potamon*—the common fresh-water crab, represented by one or two exceedingly closely related species that occur throughout all of the Mediterranean watershed and islands, and from thence eastward into Mesopotamia and southward into Egypt and the Sahara.

These common crabs, which were eaten by all the early peoples of this region as they are by the peoples there today, live in burrows along the swamps and water courses. What more suggestive of darkness than the dank burrows in the river mud which the crab excavates downward, in the general direction, at least, of the bowels of the earth?

The familiarity of the ancient Mediterranean peoples with *Potamon* is further evidenced to us by their coins, some of which bear unmistakable impressions of this "workman-of-the-river-bed." This use of Crustacea—particularly crabs, shrimps, lobsters, and crayfish—on coinage, was widespread in the Phoenician and Greek settlements. Ancient Akragas—modern Girgenti of the south coast of Sicily—took the crab as its emblem. Akragas means crab, and it was also the name of a river hard by the city and of the god of the river, too. Many very

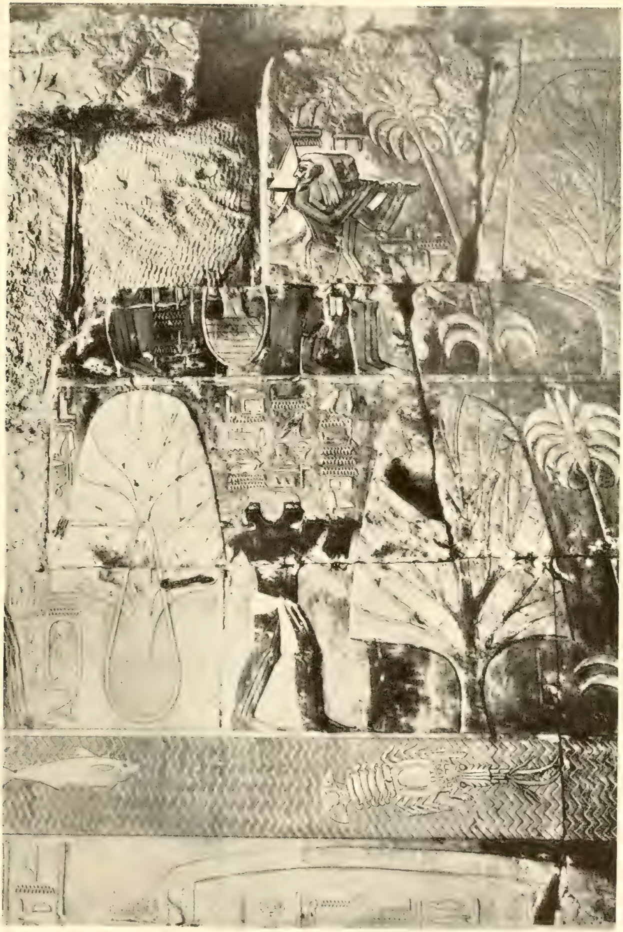
beautiful coins from Akragas, all bearing the same crab (*Potamon edulis*) are preserved to us.

One of the coins of Phaistos, among the oldest of the Cretan cities, shows Hercules with a lion skin over his arm striking at the Hydra with a club, while between his feet is the crab which nipped him at Juno's behest and which, after the hero had crushed it, the goddess raised to a place among the stars as a reward. It is thus that the Greeks explained to their own satisfaction the origin of the constellation *Cancer*.

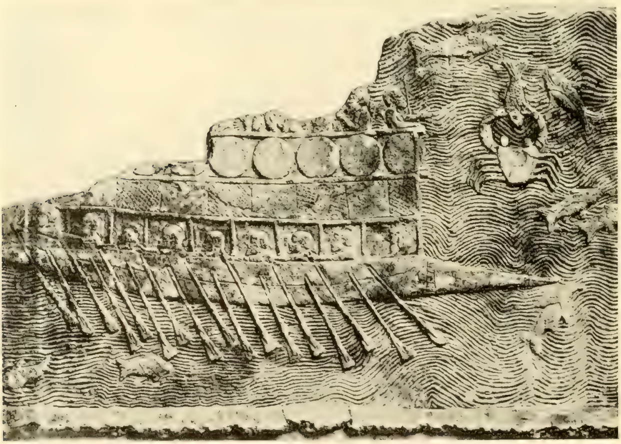
There are pictorial representations of crabs that probably antedate their use on coins. In Egypt the expedition under the auspices of Queen Hatshepsut of the XVIIIth dynasty (1580–1350 B.C.) to Punt, on the Red Sea, recorded among other things the different types of fish and some of the crustaceans found. These were drawn on the wall of the temple at Deir-el-Bahari (Plate 34).

In New York are to be seen, supporting Cleopatra's Needle, four crabs of the well known Mediterranean family Xanthidae. The obelisk itself dates from 1479 B.C., and the crabs, one would suppose, are equally old. Other very old representations of Crustacea indicative of considerable knowledge of the class are those which were done in relief, along with representations of fish, on the walls of the palace of Sennacherib, ruler of Assyria from 705–681 B.C. (Plate 35). Fragments of these old reliefs are still in existence.

The scientific study of Crustacea, as indeed of all natural history, begins with Aristotle. As he himself expressed it, "I found no basis prepared; no models to copy. . . . Mine is the first step, and therefore a small one, though worked out with much thought and hard labor. It must be looked at as a first step and judged with indulgence. You, my readers, or hearers of my lectures, if you think I have done as much as can fairly be required for an initiatory start, as compared with more advanced departments of theory, will acknowledge what I have achieved and pardon what I have left for others to accomplish."



Wall decoration in the temple at Deir-el-Bahari, recording the finds of an Egyptian expedition (about 1500 B.C.) to Punt, on the Red Sea. The lobster is *Panulirus penicillatus*. Courtesy of the Oriental Institute of the University of Chicago



Assyrian wall reliefs of river scenes.
Upper: Conquest of the tribes inhabiting the marshes of the Euphrates, showing crabs in the water.
Lower: Fragment showing crab catching a fish. After Patterson

The completeness of Aristotle's description of certain Crustacea is well-nigh recent in treatment, and nearly a dozen species can be surely identified from his data, while another six are doubtfully placed. The total exceeds that of all the species we have been able to trace from all other records of the ancient world.

From Aristotle to Linnaeus (1758), a period of nearly twenty-one hundred years, the contributors to carcinology (the study of Crustacea), good and bad, numbered less than half a hundred. In this vast span of years one can trace the evolution of the subject—barring the direct observations of Aristotle—from mere fancy, fabrication, and conjecture through observation, study, and some experimentation to the orderly classification of specimens and material as achieved by Linnaeus, who in 1758 introduced the binomial naming of animals by genus and species and brought order out of chaos.

With the publication of Linnaeus's *Systema Naturae* in 1758—a date to be remembered as the nativity, to all intents and purposes, of zoology and botany—carcinology took on the status of a science. Its development gathered momentum with the years, until now we have such a flood of data and observations as no one man can hope to master.

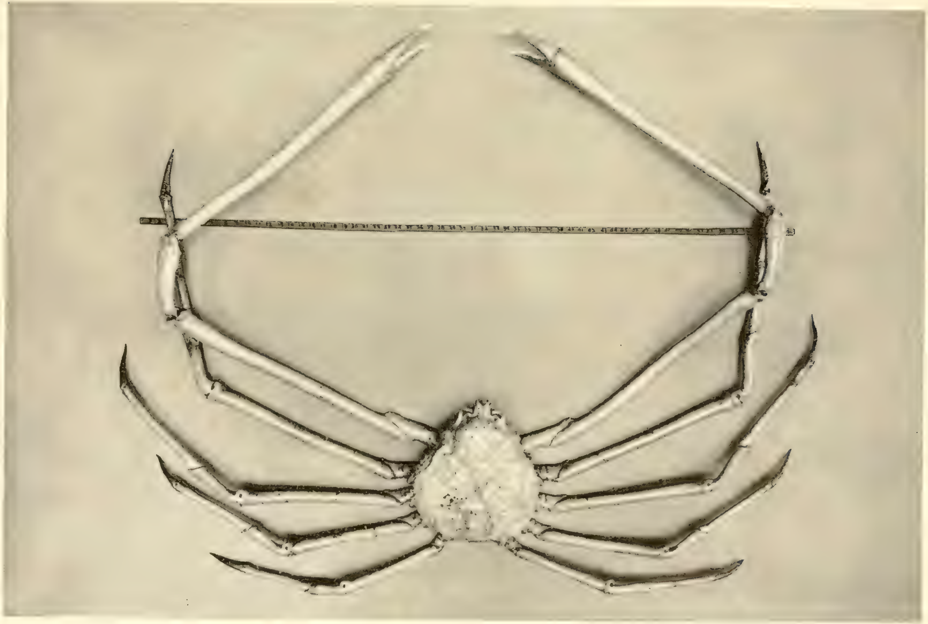
CHAPTER II

BODY ORGANIZATION AND FUNCTIONS

From the giant crab of Japan, which may span twelve feet between the tips of its outstretched claws, crustaceans scale down in size to water-fleas and copepods so minute that only a powerful microscope can discover for us their make-up and enable us to distinguish between their kinds. The edible crabs, shrimps, and lobsters, with which most of us are familiar, all belong to the most highly developed members of the class, the order Decapoda, or ten-footed crustaceans. Perhaps if we appeal to these less unfamiliar animals for a general introduction to the habits and structure of Crustacea, we shall realize that they have to accomplish the same fundamental processes to sustain life as does the human organism; and that while the mechanism they have evolved for this purpose differs from ours in some aspects, in others it is strikingly similar. And if we get on terms of intimacy with the higher Crustacea, the subsequent introduction to their more recluse relatives will prove less of an ordeal.

The Decapoda constitute a rather restricted order, in spite of the great diversity of form exhibited by their members. Superficially a crab seems to bear little resemblance to a lobster or shrimp. Yet if you examine closely any of the edible crabs that come to your table you will be surprised at how lobsterlike they are in structure. A casual inspection will reveal some common characters which will enable you to distinguish the Decapoda from the rest of the crustaceans.

Our definition of Crustacea in the previous chapter



The giant spider crab (*Macrocheira kaempferi*) of Japan. Specimen in the National Museum

began with the statement that all the members of this class have at some time in their lives a segmented body. We might, as a matter of fact, project on the screen of our imagination an idealized simplification of the ancestral crustacean, which would consist of a series of simple rings, each with a pair of appendages; something, for example,

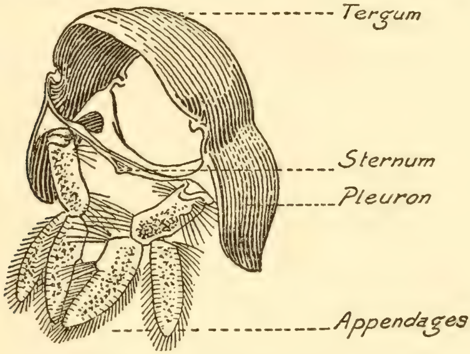


FIG. 5. Diagrammatic representation of an abdominal somite of a lobster with its appendages

like the rattles of a rattlesnake armed with legs. And back to such a simplified norm we might reduce all the complex variations of form and structure now exhibited by the thousands of known species of Crustacea: of so elemental a nature is segmentation in this class of animals. Insects have it, too, however, so that we can not use it as the sole delimiting character of Crustacea.

The factor that calls attention to the segmentation of the shrimp or lobster body is the hard shell covering of each ring or somite. Such shelly rings (Fig. 5) overlap and make an external skeleton for the crustacean like a suit of jointed armor, headpiece and all. But, though jointed, the rings are really continuous over the entire body, including the limbs. The substance of which this

body covering is made is a hornlike material called chitin, which resembles human finger nails but differs from them in being secreted by the skin—not cornified epidermis. At the joints it is thin and soft, permitting the parts to move upon one another, but elsewhere it is hardened by the deposition of carbonate and other salts of lime. Though the somites can move backwards and forwards upon one another they can not move laterally, because the soft joints are interrupted at the sides by interlocking hinge joints—a fact which prevents a lobster from swimming in any other direction than forward or backward. In retreat the lobster swims backward by flapping the abdomen vigorously, and achieves great speed—twenty-five feet in less than a second, according to one observer.

The first things to look at, then, in a proper consideration of the relationships of a decapod are its body segments or somites. We are rather apt to think of a crab as covered by a single shell or carapace, like a turtle. That, however, is because of the deceptive, great development of the dorsum of a single somite—the one carrying the jaws or mandibles. The other somites are present, also; but they are hidden under their overgrown comrade, as you will see by turning the crab over on his back.

The number of segments is an important character which distinguishes the true Malacostraca—the great subclass to which the order Decapoda belongs—from all other crustaceans. Invariably in the true Malacostraca the body is divided into nineteen segments, although sometimes two or more somites will be partially or completely fused. But the existence of a segment can often be determined by the appendages, of which every somite originally had one pair and only one pair. Thus where two or more pairs of appendages appear to be attached to but a single segment, it is certain that fusion has taken place.

Nearly all of the nineteen somites can be seen in a more or less completely segmented malacostracan like *Anaspides* (see Fig. 25, page 150). In our lobster, shrimp,

or crab the whole nineteen can generally be counted out by appendages, imperfect fusion, or by comparison with related genera in which fusion has not taken place.

Incidentally, there are two sections of the crustacean body, one at each extremity, which are generally not considered true somites. At the head this excluded por-

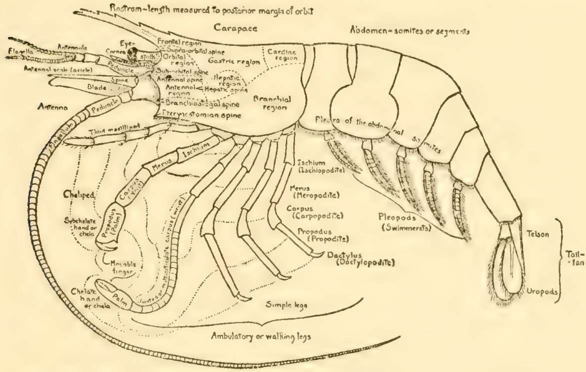


Fig. 6. Conventionalized shrimp, illustrating terms used in the description and classification of crustaceans. After Schmitt

tion is that which bears the eyes. Because of their manner of development these important sense organs are generally not classed as appendages, wherefore the section bearing them is not a somite in the true sense of the word. At the other extremity the section not admitted to the rank of a true segment is the tailpiece, or telson—for it is always devoid of appendages.

So restricted, we have in the Eumalacostraca nineteen true, typical, appendage-bearing somites, not including the eye-bearing portion of the body and the telson. The number is constant and serves as a basic character for the classification of the group.

A glance at the accompanying diagram (Fig. 6) will

show better than a volume of words what a typical decapod—a shrimp—looks like. The body is divided into three main regions—head, thorax, and abdomen. The head and the thorax are coalesced and are covered dorsally by the overgrown mandibular segment already referred to, forming what is technically known as the carapace.

If the shrimp had a neck it would be much simpler to understand why the first five segments—Nos. 1 to 5—are called the head. But at least they occur at the proper end of the creature and carry many of the sense organs. These segments are fused, but we can see that there were five of them originally by counting the appendages. The first two pairs of appendages are the crustacean's feelers, called respectively the first antennae, or antennules, and the second antennae, or antennae proper. This possession of two pairs of feelers is the character that at once distinguishes crustaceans from insects: insects have but one pair of feelers; crustaceans always have two. Between the feelers and the third true somite, the eye-bearing element occurs. The third pair of appendages are the mandibles, or jaws proper; while the fourth and fifth pairs are the accessory jaws, called maxillae or sometimes (if designated separately), the maxillula and maxilla, respectively.

The next eight segments—Nos. 6 to 13, inclusive—make up the thorax. As an indication of the arbitrary division between thorax and head, we find that the first three pairs of appendages in this section are comparable to the last two of the head; that is, they, also, are accessory jaws, called maxillipeds (foot jaws).

The five segments numbered 9, 10, 11, 12 and 13 carry the five pairs of legs from which the Decapoda derive their ordinal name.

The abdomen, with six somites, brings the total number of somites in the shrimp to the specified nineteen characteristic of our true Malacostraca. Appendage pairs Nos. 14, 15, 16, 17, and 18 are the pleopods, or swimmerets.

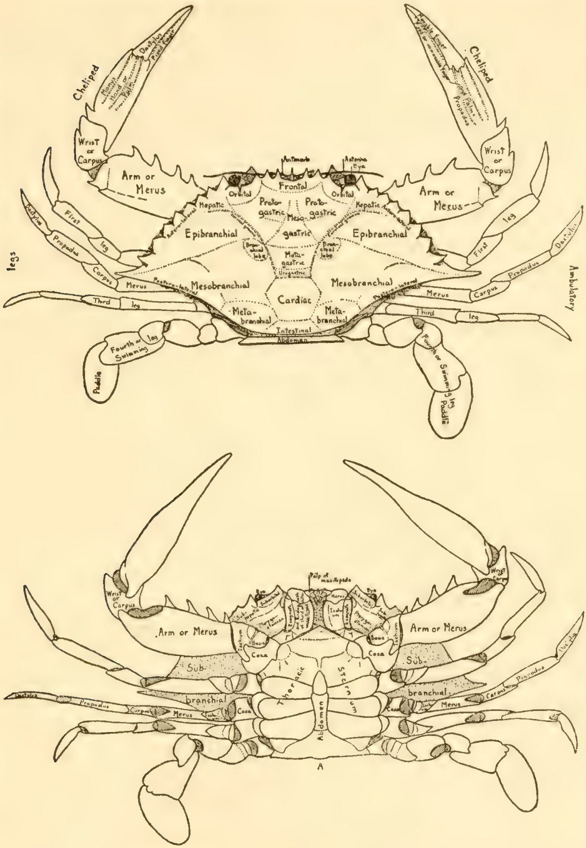


FIG. 7. Diagrammatic representation of the edible blue crab (*Callinectes sapidus*), dorsal (upper) and ventral (lower) views, illustrating terms used in the description and classification of decapod crustaceans. After Rathbun

The last or 19th pair of appendages, are the uropods and when present they constitute, with the telson, the tail fan. The telson, or tailpiece, is, of course, part of the abdomen, though not of true somitic rank.

We are apt to think of the crab as without a tail. This does him an injustice; for though flexed and flattened and practically devoid of meat, a normal abdomen or tail is present.

So much for the number and arrangement of our crustacean's appendages. It may increase our respect for the appendages to learn something of their variety of form and function.

The mandibles, which most resemble teeth in some crustaceans, serve to cut up into bits that may be swallowed such pieces of food as may be presented them by the other mouth appendages.

The ten pairs of appendages which follow the mandibles —Nos. 4 to 13, inclusive, in the true Malacostraca—have more or less generally allotted to them, to quote Stebbing, the functions of "tasting and pasting, biting and fighting, grasping and clasping, walking and a kind of inarticulate talking, swimming, burrowing, house building, besides the automatic services which they render to the eggs in the brood pouch and to the animal's own respiration."

To match such diversity of function we may rightly expect some diversity of form in these appendages. Some, in fact, are a kind of jaws—organs of the mouth—while others are a kind of arms or legs—organs of the trunk. But whatever their function or form, all appendages, from antennules to uropods, seem to be reducible to a common pattern consisting of a stem and two branches—one inner and the other outer. The inner is the main branch of the appendage, and the outer is often left rather primitively flagelliform or lashlike.

Both stem and branches are jointed. Three joints are theoretically the normal number for the stem or peduncle; but usually there are but two, or more rarely only one.

The number of joints in the branches may vary considerably, five being a normal number for the inner branch of the appendages of the head and thorax.

With so many units to work with, it is no wonder that a crustacean species can fashion almost any tool its needs demand. To make pincers, for instance, the only thing it needs to do is to draw out one joint beyond the point where the next is attached to it. This is how the great crushing claw, or chela, of a crab or lobster is made. Whenever an appendage develops a chela it is said to be chelate.

Often where an appendage is used as an oar both branches are developed and composed of many joints, each furnished with a fringe of hairs (Fig. 8, No. 1), so that the whole makes an effective swimming organ. The pleopods of the lobster are so constructed (Fig. 5, Appendages).

A crustacean can cast off a limb and grow a new one in its place. This provision serves him in good stead as a means of escape from his enemies. Such a voluntary break in the lobster's appendages takes place at the juncture of the second and third joints of the stem. At this point the internal cavity is crossed by a transverse partition having only a small aperture, through which the nerves and blood vessels pass. The lobster produces the break by a spasmodic contraction of the limb muscles. The partition facilitates the formation of a blood clot at the small aperture, and this stops the bleeding. The growing of a new limb begins at once with the formation of a bud beneath the scar left by the breaking off of the old one. The bud takes on the shape of a limb, which after a few molts can not ordinarily be distinguished from its predecessor.

Thus we come to the subject of molting. We have pointed out that the decapod is completely inclosed in a more or less continuous hard-shelled covering hinged like a suit of armor. This hard shell is incapable of expan-

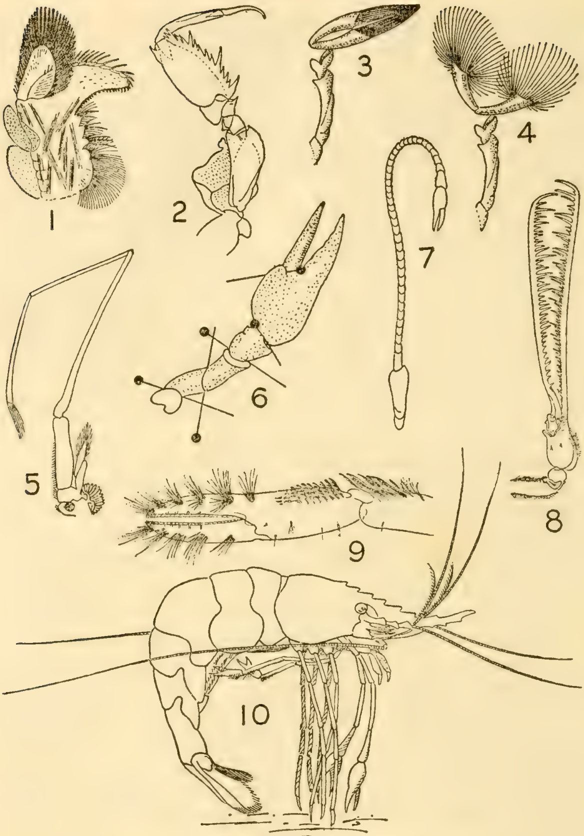
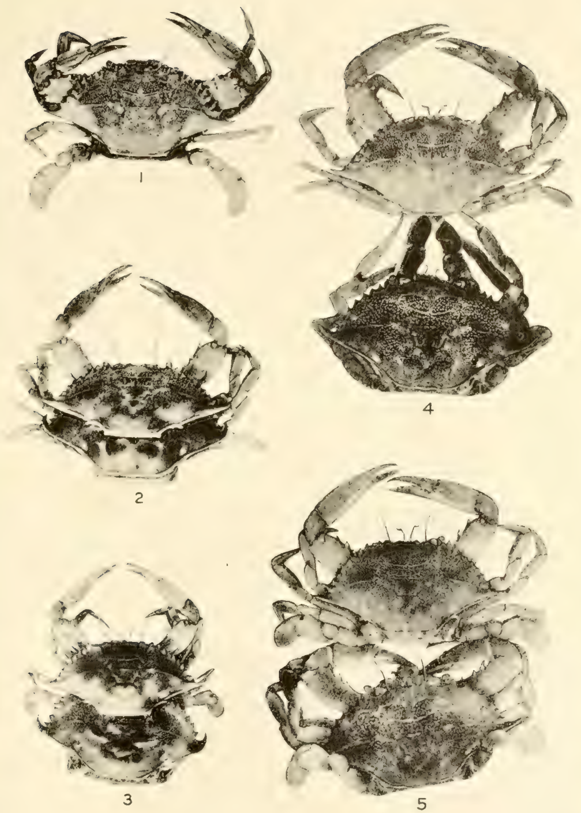
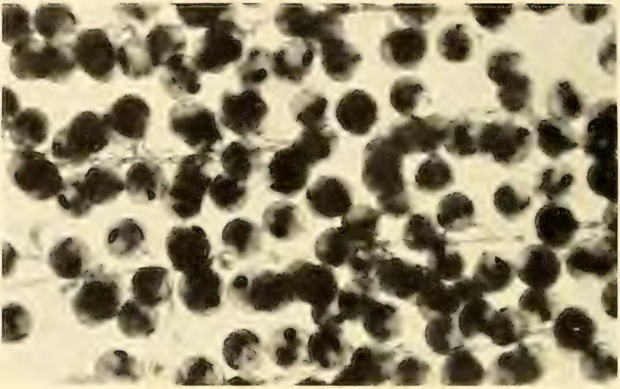
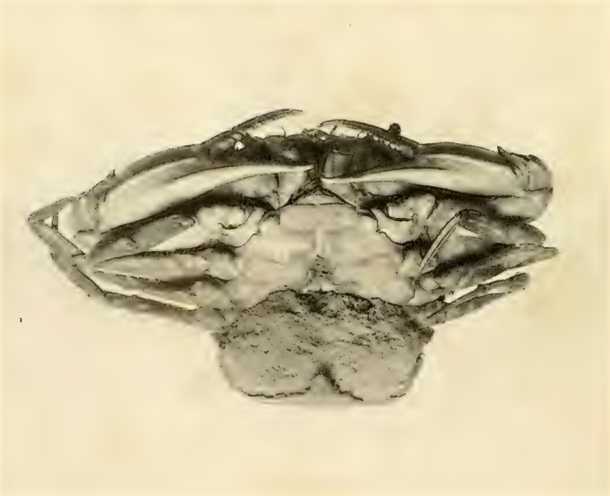


FIG. 8. Diverse appendages. 1, oar foot; 2, amphipod claw; 3, 4, claw of shrimp with brush of hairs for catching small organisms; 5, euphausid foot; 6, crawfish claw (pins show axes of articulation); 7, second leg of shrimp; 8, claw of lobsterlike decapod; 9, claw with cleaning brushes; 10, brushes in action



Successive stages in the molting of the edible blue crab (*Callinectes sapidus*). Courtesy of the Bureau of Fisheries





Female blue crab and eggs

Upper: Photomicrograph of eggs of the blue crab attached to hairs of swimmerets (x 120). Lower: Gravid female (*Callinectes sapidus*). Courtesy of the Bureau of Fisheries

sion, of course, so in order to find room for an increasing girth the crab, lobster, or shrimp has to shed his housing periodically. He does this by pulling himself through a transverse slit across the hinder "waist line" of the shell, much as we might withdraw from a one-piece suit through a slit across the small of the back.

The edible blue crab of the Atlantic coast, whose molting has been rather extensively studied, gives warning of an approaching molt several days in advance. A black line appears just within the thin outer and back margins of the outer segments of the swimming legs. This line changes to white and then to red, two or three days before the molt. Fishermen call the crab in this condition a "peeler." At the moment of molting the carapace, or shell-like covering of the head and thorax, begins to move away from the abdomen, and a crack appears in each side of the shell, extending almost to the mouth. The posterior part of the body begins to protrude through the gap thus made. At this time the crab usually lies motionless, but he can swim quite actively if disturbed. The remainder of the molting process requires about fifteen minutes. The carapace is lifted higher, the swimming legs begin to be withdrawn by rhythmic throbbing movements, and the body protrudes more and more from the shell (Plate 37).

When the crab has freed himself completely from his old housing, he is that table delicacy known as a soft-shelled crab. He remains so for a short time only, for within forty-eight hours the new shell has gotten almost too hard to permit of his use as a "soft-shell." As a consequence, most of the commercial soft-shelled crabs are caught as peelers and kept in floats until a few hours after molting, when they are marketed. At the time of shedding, the soft, new shell permits of expansion, and a blue crab that measured three and a half inches in width of carapace before a molt may measure four and a half inches four hours afterwards. This rapid increase in size results in large measure from the absorption of water. The harden-

ing of the new shell is due to the deposition of lime salts. Normally, all decapods seem to eat their discarded housings immediately after molting, a habit which may be nature's device for furnishing the large supply of lime salts needed for rapid hardening of the new shell.

Molting is, of course, an exhausting and dangerous process: and considering the defenselessness of the crustacean while it is going on it must be attended with a

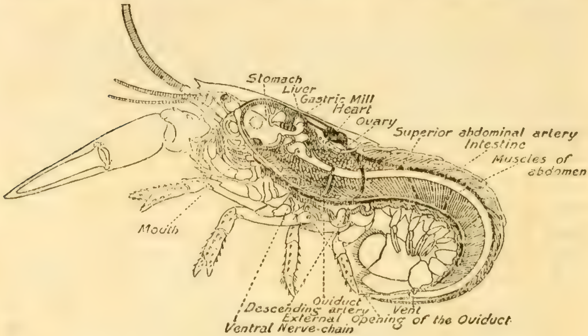


FIG. 9. Longitudinal section of a lobster (*Homarus americanus*) to show its principal internal organs

high mortality. As one author has expressed it, molting is the price these animals pay for their protective armor. The epicure, at least, may be grateful for it.

When a malacostracan molts, it sheds the lining of its stomach and of a part of its intestinal tract as well as its shell. The linings are continuous with the shell and composed of the same substance, chitin. The stomach, incidentally, is an extraordinary mechanism. It consists of two chambers. The chitinous lining in places is thickened to form a system of plates or "millstones," which by muscular action engage with three strong teeth set in the narrow opening between the two chambers to grind up

the food ingested. Quite aptly the apparatus is called the "gastric mill" (Fig. 9).

The decapod heart lies in the animal's back under the carapace. From it a system of arteries carries the blood to the body tissues. Of veins as we understand them crustaceans have none, but the blood finds its way back to the heart by ill-defined channels which open into the pericardium, or space surrounding the heart. From this it is let into the heart by six valves, which admit of its entrance but not of its exit.

On its way back to the heart some of the blood passes through the gills, which of course, take the place of the lungs of higher animals. A lobster has twenty gills on each side of the thorax under the carapace. This position insures protection and yet permits a constant supply of water to pass over the gills. In fact a special plate or "bailer" called the scaphognathite lies in front of the gills and by maintaining a constant motion during life causes a regular stream of water to flow forward over them. Each gill looks much like a feather with thick barbs. The blood streams through the minute channels in the stem and barbs and is separated from the water only by a thin tissue or membrane, which readily permits absorption of oxygen and discharge of carbon dioxide by the blood. The purified blood returns by a series of inner channels to the pericardium and the heart.

The higher crustaceans have rather the hint than the reality of a brain in a nerve center in the front of the head that sends nerves to the eyes, antennules, and antennae. The principal part of the nervous system of these creatures is the ventral nerve chain, which runs along the under side of the body and from which nerves lead off at intervals to the various organs and appendages.

All the Decapoda and most other Crustacea reproduce as do vertebrate animals, namely, by the union of the two sexes. The reproductive organs of the decapods are situated in each sex in a comparable position, to either side and

just below the heart. The external openings usually occur on or near the basal segments of the last pair of legs in the males, of two from the last pair in the females. The female often has a special organ, called a sperm-receptacle, between the last pair of legs, wherein she stores the sperm from the male until the eggs are ready to be deposited. In most true Malacostraca the female carries the eggs after extrusion until they are hatched—for perhaps a ten-months period. They are usually cemented in bunches to the swimmerets, and one lobster may carry from 3,000 to 100,000 eggs.

The parent crustacean who knew his own child would indeed be wondrous wise, for most young at the time of hatching bear but slight resemblance to the authors—male or female—of their being. In fact some young go through a metamorphosis as extraordinary as the change of a maggot into a fly or of a caterpillar into a moth or butterfly. Often the transformation involves several stages, each strikingly different from the others—so different, in fact, that naturalists of an earlier day were quite understandably deceived into believing that each stage represented a different animal. And they were not easily convinced of their error.

Our Decapoda exhibit various degrees of metamorphosis as well as no metamorphosis at all. The workman-of-the-river-bed, *Potamon*, the crab that we found elevated to the zodiac by the Babylonians, hatches from the egg as a replica of the adult crab. The common fresh-water crayfish hatches with all the appendages of the adult except the first pair of swimmerets and the uropods. The lobster, though it goes through several larval stages, might still be recognized for what it is when hatched; but no one would dream that the newly hatched porcellanid crab shown in Figure 10 was the offspring of the adult into which it grows.

The simplest form in which any crustacean may hatch from the egg is as a nauplius larva. The nauplius has a

tiny, rounded body wholly unsegmented but carrying three pairs of movable appendages: the antennules; the antennae; and the mandibles, or better, mandibular legs. All three pairs of appendages serve to propel the larva through the water.

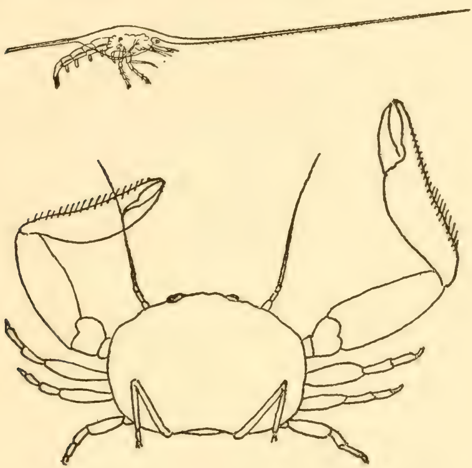


FIG. 10. Last zoeal larval stage (x 10) and a full-grown adult of a porcellanid crab (x 2½) (*Porcellana macrocheles*). After Faxon

The nauplius is the link which ties together all crustaceans into one great family. It would appear that the nauplius, from its prevalence throughout the Crustacea, was established as a larval form at a period of development prior to the divergence of the existing groups. All crustaceans go through a nauplius stage, either suppressed within the egg or as the first stage after hatching.

The subsequent metamorphoses through which one and another crustacean species passes are numerous and re-

quire too technical an explanation to find a place in an account of this kind.

Perhaps nothing would break down our sense of the strangeness of crustaceans so much as to discover that their impressions of the external world were received through organs of sense comparable to our own. To ask, then, whether the Crustacea see, hear, feel, smell, and taste as do vertebrate animals, is a fair question and bespeaks a fairer answer than it is, perhaps, possible to give. Naturally, more research on this question has been done on the larger and more highly developed Decapoda than on the lower crustacean forms. It is Herrick's opinion that in the lobster "the sense of hearing is probably absent and that of sight far from acute, but this animal possesses a keen sense of touch and smell, possibly a sense of taste, and is quite sensitive to changes of temperature and light."

Of actual organs of special sense the lobster seems to have only two kinds: a pair of eyes, and sensory hairs or setae distributed over the entire body and appendages. Though the eyes are rendered prominent by their size and their position on stalks, vision is never keen and is probably almost lacking in bright light. Like the eyes of insects, those of lobsters are compound, with perhaps as many as 14,000 facets; each of these flashes an impression to the optic nerve, so that the image registered there is a mosaic of 14,000 units. The lobster is by preference a night prowler and in addition confines his activities during the greater part of his life to dimly lit sea bottoms; so that we may conclude that he places but little reliance on his organs of sight but prefers to do even his "seeing" with the sensory hairs which are by all odds his most useful and versatile sense organs.

Without taking undue liberties with the English language, we may say that the lobster smells, tastes, and even does something that corresponds to hearing by means of hairs. His hairs, of course, are not the relatively in-

sensitive filaments that grow out of the human head: they are hollow shafts of chitin—the substance of which his entire body covering is composed—and inside them run nerves which transmit sensations to the central nervous system. Thus we see that the principle of the crustacean organism in so far as it is adapted to sense perception is exactly the same as that of our own organs of taste, touch, and smell.

The function of smelling—which in Crustacea is difficult to distinguish from that of tasting—is performed by the so-called olfactory setae, which are restricted to the first antennae and the mouth parts. They are the hairs sensitive to chemical stimuli. As the currents waft fine particles of the lobsterman's bait to the lobster in his hole or on the prowl, these olfactory setae catch the scent and lead the victim to follow the trail to the trap.

The sense of touch functions by means of the tactile setae which are scattered all over the rest of the lobster's body. From fifty thousand to a hundred thousand are found on the big claws and slender legs alone. Whipping the water with his antennules, trying every crevice with his antennae and big claws, the lobster smells and feels rather than sees his way. Sensitivity to touch is keener in the hairs of certain regions of the lobster's body—such as the tips of the antennules—than in those of other regions, just as in man this sensitivity is keener in the finger tips than in other parts of his body.

The lobster probably does not hear in the sense that mammals do, and he has no organ comparable to the ear of higher vertebrates. But his setae do respond to vibrations in the water just as our ear drum responds to vibrations in the air. The lobster has, however, a pair of organs which were formerly regarded as true ear sacs, but which are now recognized to be organs of equilibration. These organs, called statocysts, enable him to swim in an upright position. They occur as cavities in the basal segments of the first pair of antennae and are furnished

with several hundred minute hairs, or setae, each richly supplied with nerves. A tiny aperture gives access to each cavity and permits the entrance of microscopic grains of sand, many of which are glued to the tips of the minute setae and then serve as weights to inform the lobster of the direction of the force of gravity. The whole subject of hearing in Crustacea is rendered especially absorbing because of the presence in many species of what appears to correspond to a voice. Because of its interest we will devote some time to this subject later (page 192).

To conclude our introduction to the lobster's physiology and psychology we need only say that he is excessively pugnacious; that he is a willing cannibal and will as readily eat his own progeny as his own brother if strength will permit it; that he shows enough intelligence upon occasion to stalk his prey; and that he has been known to store up food, as a dog will hide a bone, for future need. We may now, I hope, go on to meet his relatives as if they were the family of an old friend.

CHAPTER III

THE FAMILY ALBUM

EVERY trade and profession has its special vocabulary, and carcinology is no exception. Unfortunately we can not discuss this vast society of little-known creatures without using their names, or at least the names of the large groups into which they are divided. Earlier carcinologists split the class into two subclasses, Malacostraca and Entomostraca, but the latter included such a pageant of diversity that it had to be replaced by four subclasses for the sake of better definition. The classification is now as follows:

CRUSTACEA (Class)

	Subclass	*Series*	*Division*	*Order*
(Entomostraca)	Branchiopoda			Anostraca
				Notostraca
				Conchostraca
				Cladocera
	Ostracoda			Myodocopa
				Podocopa
	Copepoda			Eucopepoda
				Branchiura
	Cirripedia			Thoracica
				Rhizocephala
	Malacostraca	Leptostraca		Nebaliacea
		Eumalacostraca (true Malacostraca)	Syncarida	Anaspidacea
			Peracarida	Mysidacea
				Thermosbaenacea
				Cumacea
				Tanaidacea
				Isopoda
				Amphipoda
			Eucarida	Euphausiacea
				Decapoda
			Hoplocarida	Stomatopoda

The Decapoda, whose guidance we have been following into the physical and psychological mysteries of the Crustacea, belong to the subclass Malacostraca, the great majority of whom, called true or Eumalacostraca, have the grace to keep the number of body segments or true somites at nineteen, a character which makes for ready identification of the membership. All the other subclasses have a number of body segments greater or less than nineteen—never nineteen. And this diversity of segmentation is a symbol of the diversity to be found in all their structural characteristics.

Branchiopoda

The Branchiopoda, first of the subclasses to claim our attention, breathe—so to speak—through their feet. The name means "gill foot." These feet are usually foliaceous or leaflike, divided into a number of lobes, each with a gill plate on the outer side which serves as a respiratory organ like the gills of the higher Crustacea. This peculiarity of "foot breathing" is about the only character common to the four radically different orders that make up the Branchiopoda, though the trunk segments are generally distinct and the trunk limbs alike.

Three of the orders, Anostraca (shell-less), Notostraca (shell-backed), and Conchostraca (mollusk-shelled), are all fresh-water forms. By some these three orders are grouped together under the name phyllopods, in contradistinction to the remaining order—Cladocera. Though they are the only Crustacea that have no known truly marine forms they have no aversion to salty water. One of them is the brine shrimp *Artemia*, the only animal that flourishes in the Great Salt Lake of Utah and similar bodies of water high in salt content. Not only do the adults thrive in these saline waters, but their eggs persist after all the water has evaporated and only salt remains. When the salt is again dissolved, by natural or artificial means, the eggs hatch into a new generation of *Artemia*.

It is recorded that some mud scraped from the bottom of a dried-out salt-water lake of Algiers was carried to France and three years later dissolved in sterilized water, whereupon there hatched out artemias known to inhabit the Algerian seasonal lakes during the rainy season.

Nearly all, if not all, of the phyllopod Crustacea and many other entomostracans—living, as they generally do, in evanescent bodies of water—are endowed in the egg stage with a remarkable drought-resisting faculty. In fact, it is probable that eggs not subjected to some sort of drying fail to hatch—a most providential arrangement; for if it were possible for eggs to hatch without undergoing the apparent vicissitude of a drought, such eggs as remained when the pool became dry—and when the adults, in consequence, died off—might not have the resistance to endure until the next rainy season. Thus the species would be wiped out with the first complete evaporation of its particular little puddle cosmos.

Usually two kinds of eggs are produced by these forms: the so-called summer eggs, purely vegetative and asexual, produced in large numbers and frequently throughout the favorable seasons or periods; and the more resistant dry-season or winter eggs (as the case may be), fewer in number but of greater vitality, and—as a rule, but not always—sexually produced by cross fertilization. In *Limnadia*, among the conchostracan phyllopods, as well as in certain species of ostracods, no males are known or have ever been discovered. Even in the notostracan, *Apus*, males are often of such rare occurrence that their discovery is worthy of note.

The typical anostracan, so-called because of its lack of a carapace, is the fairy shrimp (Fig. 11), of temperate climes. Some fairy shrimps attain a length of an inch or more. The true fairy shrimps are fairies in every sense of the word—graceful and easy of movement, and clothed with delicate draperies (as one might term their many foliaceous limbs),

often so beautifully transparent that the shrimps seem almost to be endowed with the fairies' magic cap of invisibility. Such colors as some of them exhibit are largely the result of refraction—evanescent, iridescent greens and blues, which appear at times on some of the appendages

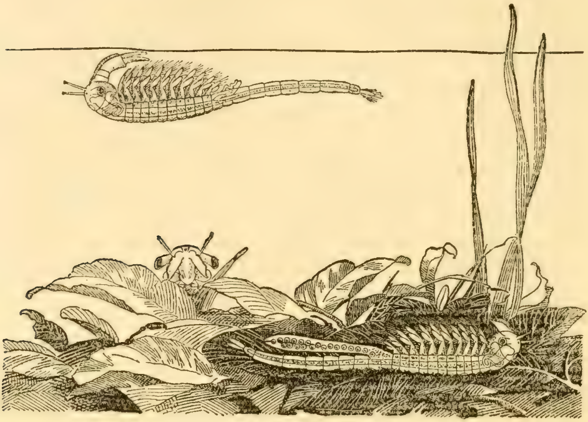


FIG. 11. Fairy shrimps (*Branchinecta paludosa*) in a pond. Female with egg sac among leaves; male swimming and feeding at the surface in normal inverted position

over a ground of translucent creamy white with reddish trimming. Though common in many parts of the world, fairy shrimps are seldom seen except when especially sought after. Their occurrence, too, seems largely subject to all the vagaries of *Apus*, recounted below.

Apus (Fig. 12), which belongs to the order Notostraca, a name that refers to the shell-like carapace of its members, looks remarkably like a small horseshoe crab. It is the giant of all branchiopods and may measure nearly

three inches in length. Contrast this with the one hundred and twenty-seventh of an inch, which *Allonella*, one of the Cladocera, measures when full grown. The chief claim of *Apus*, however, to popular attention is its in-

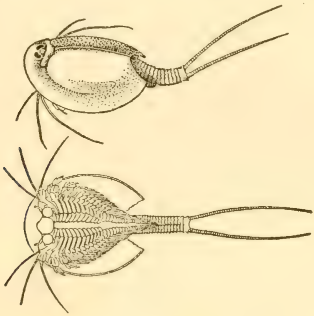


FIG. 12. *Apus* giant among the branchiopods. Lateral and ventral views. Adapted from Sars

constancy of habitat. Though not uncommon from year to year on the continent of Europe it makes some very curious skips and jumps in its seasonal appearance, and one can not definitely count on finding it in the same locality two years in succession. Frequently it fails to appear in a given area for a number of years; and once a period of fifty-seven years elapsed from its recorded occurrence in Great Britain in 1850, as published by Baird, to its reappearance in the southwest corner of Scotland in 1907. That, furthermore, is the only rediscovery of it in Britain from that day to this. This sporadic occurrence keeps *Apus* from becoming the economically valuable form that its individual bulk and great numbers would otherwise make it. What accounts for this curious phenomenon, no one knows.

The third phyllopod order, the Conchostraca (Fig. 13), gets its name from the development of the carapace of its members into a bivalve shell, completely inclosing the body and limbs and closely resembling the shell of a

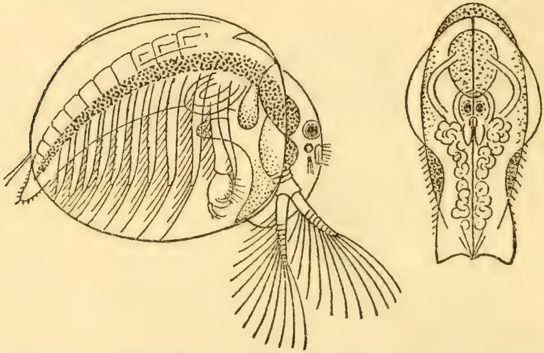


Fig. 13. Branchiopod (*Limnetis*) with a bivalve carapace. Lateral view of female and frontal view of male (x 10). After Sars

small mollusk. A similar development has taken place in most of the Cladocera, although in these Crustaceans the head is left free.

"Water-fleas" the Cladocera are named, from their jumping mode of progression. They have none of the erratic characteristics of the phyllopod *Apus*, and though of very small size, even microscopic, they occur in such great numbers that they furnish the basic food supply to many of the commercial fishes of the Great Lakes. Indeed some species of Cladocera are marine and form such considerable swarms at sea that they must contribute largely to the food of salt-water fishes likewise, though here they give precedence to members of the subclass Copepoda.

Daphnia pulex, one of the best known cladocerans, bears

in her specific name the brand of her resemblance to the flea. Her diminutive size hides much delicate beauty from our gross vision. Under the microscope she can teach us a great deal about the reproductive habits of the branchiopods. Something has been said of the two sorts of eggs laid by members of the preceding subclasses. *Daphnia*, in common with the other cladocerans, carries her eggs around in a brood pouch inclosed by the dorsal part of the valves of her carapace (Fig. 14). Here

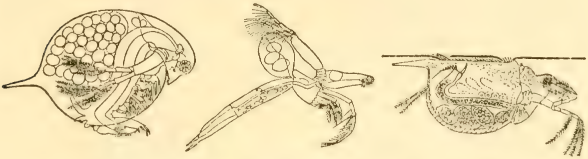


FIG. 14. Representative cladocerans. Left, female *Daphnia pulex* (x 6). Center, female *Leptodora kindtii* (x 1½). Right, female *Scapholeberis mucronata* (x 20), using surface film of water as a support. After Keilhack, Pearse, and Scourfield

is the nursery in which the eggs develop and where the young hatch out in a form not unlike the parent and are sheltered till fairly well grown before being sent out to seek their own livelihood. Thus it is that we find no free-swimming larval forms among the Cladocera. The offspring are nourished in quite a remarkable manner. For the long period of their sheltered existence, the egg yolk with which they hatched into the world would not alone suffice, so as they grow up they feed, also, upon a secretion from the walls of the brood chamber.

This is the course of the parthenogenetic young, which consist usually of several successive generations of females. But sooner or later, with the approach of unfavorable conditions, such as winter or the drying up of the body of water in which they live, true sexual males and females hatch out. These in turn unite to produce

fewer (usually one or two) but larger eggs, heavy with much yolk and with a thick, resistant shell. Like the other eggs, these, too, pass into the brood-chamber, which now becomes more or less modified and thickened. In *Daphnia*, particularly, this transformation becomes quite marked; the valves of the carapace take on a peculiar shape like a saddle; and so the carapace in this genus bears the technical name of ephippium derived through the Latin from two Greek words meaning "on a horse." The purpose of this modification is seen in the next molt, when the ephippium becomes detached from the rest of the shell and closes snugly about the eggs it is to guard, thus protecting them until the next favorable season.

These winter eggs, like those of other lower Crustacea, are very drought resistant. Mud taken from the dried-up Pool of Gihon, at Jerusalem—a pool whose history goes back some twenty-five hundred years—was moistened, and there hatched out not less than seven species of Crustacea, of which at least two were new to science at the time. One bit of mud from this pool was alternately moistened and dried out in the laboratory year after year for twenty-four years, thus simulating the wet and dry seasons of its normal environment; and each year until an accident terminated the experiment, new Crustacea hatched out. Other portions of this dry mud were laid away for nine and ten years and then moistened, whereupon Crustacea hatched out.

Of the Cladocera, only a few are not "shelled." The carapace of shell-less forms is transformed into a distinct and conspicuous brood pouch. These aberrant members of the order present such radical departures from the usual cladoceran form that they constitute a group apart, in which is included *Leptodora kindtii* (Fig. 14), without doubt the largest cladoceran, the female reaching a length of nearly three-quarters of an inch. Any other species, when full grown, is of good size if it measures as much as a sixteenth of an inch from head to tail.

Some cladocerans have adjusted themselves to a life in the mud, and the shells of these are often overgrown with algae. But adaptations of an extraordinary nature have been developed by the species that lead a swimming existence to enable them to minimize the energy expended in keeping afloat. A few, including *Scapholeberis* (Fig. 14), hold themselves to the surface of the water by making fast to the surface film. For this purpose they possess specially modified, water-repellant scales and setae on their ventral surfaces. Swimming in their normal position, back downwards, they pierce the surface film and hang thus, drifting about, foraging along the surface of the water at will or releasing their hold to dive readily to the bottom. Swimming ventral side up seems to be the normal method in many, if not most, of the caldoceran and phyllopod crustaceans.

Advantageous as the surface film is to *Scapholeberis*, it is deadly to numerous other less well adapted Entomostraca, including *Daphnia*. If one of this genus happens to break through the surface film, it is almost as serious in its consequences as for a man to fall out of a third-story window; for upon penetrating the film it tends to fall over on its side, perfectly helpless in the powerful and relentless grip of the surface tension of the water. This is the same force that enables a steel needle to float in a glass of water. The only escape for *Daphnia* from such a hopeless condition lies in the release that a violent disturbance of the water might afford, unless the animal happens to be about to molt. In such a happy chance, like the thief that escapes by leaving his coat in his pursuer's hands, she is able to slip out of the old shell or chitinous housing, which remains floating at the surface of the water, while, newly molted, she regains the safe, cool depths. Helpless individuals of this genus have been observed at times in such numbers that they formed a scum upon the surface of the water, many square yards in area.

Ostracoda

Abundant in all seas and lakes and in almost all bodies of water, down to the merest roadside puddle, the Ostracoda (Fig. 15) probably stand next to the Copepoda among Crustacea in their importance to zoological economy. They

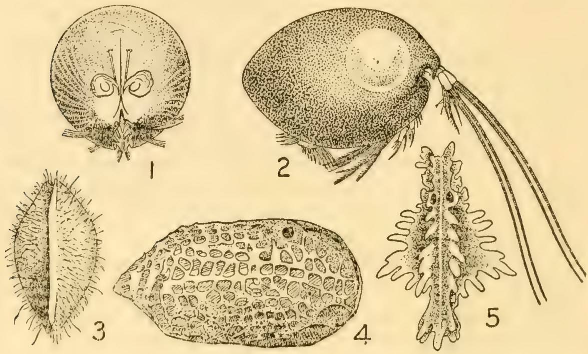


Fig. 15. Representative ostracods. 1, frontal view of a female *Gigantocypris*, largest of the ostracods (natural size); 2–5, other species (much enlarged.) After Müller

often occur in such teeming numbers as to lend color to the water. Some of them inhabit great altitudes, one species (*Cypris altissima*) having been found in a pool fed by melting snow 12,000 feet above sea level.

The great depths of the ocean have yielded the largest known ostracod. This is appropriately labeled *Gigantocypris*; for it is nearly an inch in length, which makes it a giant indeed as compared to some of the really small forms which measure only a hundredth of an inch over all.

Among Crustacea the Ostracoda are remarkable for the small number of their appendages and their unsegmented or, at best, very indistinctly segmented body, inclosed in a bivalve shell fashioned from the carapace.

Few other crustaceans are so completely encompassed by their housings. So much do they resemble small mollusks that frequently we are asked to identify the tiny "shells" this or that correspondent has unexpectedly found in some body of water.

But few as the ostracod's appendages may be, they are very powerfully developed and fulfill all the essential functions performed by the more generous number with which other crustaceans are endowed. Ostracods depend on the first and second pairs of antennae for a variety of services. In some forms these are the only appendages that protrude from the shell. Aside from their sensory function, they are the locomotive organs, and most efficient ones at that, whether the mode of progression be swimming, creeping, or burrowing.

Of the food and feeding of ostracods there is still ever so much to be learned. The more closely observed fresh-water forms seem to be omnivorous, subsisting upon almost anything that comes to hand, living or dead, animal or vegetable. Marine forms, though more difficult to observe, seem to feed largely on diatoms and other plants of the sea and shore. Carnivorous tendencies crop up in some of them; but all in all, by mere press of numbers, they must play an enormously important role as scavengers and as intermediates in the conversion of food material into a shape utilizable by larger animals. Certain species suck the juices of marine plants, for which purpose their upper and lower lips are organized, with the jaws, into a peculiar sucking proboscis. Incidentally, the ostracods that parasitize other animals have a similar adaptation. Only a few such parasitic ostracods are known, one having been taken from a fish, a second from a sea-lily, and two others from different crustaceans.

Some marine ostracods have been found with the remains of copepods in their alimentary tract. These species have taken a leaf from the birdlimer's book and ensnare their prey by means of a sticky secretion spread over

the fore part of the shell. Here any copepod that comes in contact with it is held fast, much as flypaper holds a fly. The glands of ostracods and their secretions are quite a study in themselves. Certain genera—*Pyrocypris* and *Cypridina*—are even luminous, thanks to a phosphorescent secretion which they can expel in clouds and so possibly foil a pursuing enemy. In others the fluid expressed from the glands serves to agglutinate the sand in which the ostracods burrow, and so provide their builders with definite tubular retreats. Others have a spinning gland, from which issues a sticky substance that quickly hardens and forms a thread. With this the ostracod, after the manner of familiar spiders, weaves a network to secure himself to his immediate surroundings or to enable him to climb about where otherwise his foothold would be precarious.

In common with a number of other Entomostraca, many ostracods reproduce parthenogenetically; that is, the females bear eggs which are capable of hatching and producing the succeeding generation of ostracods without the intervention of a male. Under experimental conditions in an aquarium, successive generations of females have been kept going for as long as eight years in one stretch. In fact, males of some ostracod species have never been found. Like our branchiopod water-flea, ostracod mothers may carry the eggs and sometimes even the young. Often the eggs are deposited on seaweeds, or merely shed into the water.

In vitality, also, the eggs of ostracods share honors with those of other fresh-water entomostracans, remaining viable in dried mud for years. G. O. Sars, of Norway, one of the foremost students of Entomostraca of all time, made a practice of soliciting bits of puddle, pond, and ditch bottom from all parts of the world. He was thus able to hatch and describe no end of new and unusual species of ostracods without the expense entailed by special expeditions in search of them.

But ostracods are unique in that even some of the adult forms, in spite of extreme dessication, may be brought back to a condition approaching normal by soaking them in water, though they may never actually come to life, as do the eggs on hatching. In the charming words of T. R. R. Stebbing, "Their delicate little corpses dry up within their own organic sarcophagus, and need no embalming to make them inoffensive. They remind one of that romantic country in which the old men never died but only shrivelled, and could, by process of steeping in hot water, be occasionally revivified to answer the enquiries of a younger generation."

Copepoda

Some of the mighty whalebone whales—among the world's largest mammals—and fish fry so small as to be microscopic are alike beholden for their existence to copepods, the oar-footed crustaceans. More fish and other aquatic creatures feed on these tiny crustaceans than on any other one kind of animals known. The copepods, in the main, form the base of the pyramid of marine life, transforming, as do the ostracods, the microscopic vegetable life of the sea and inland waters into food which can be utilized by animals larger than themselves. In the sea the copepods have no rival as food for fishes, and even in the Great Lakes they run the cladocerans a close second. The copepods are therefore of more than mere academic significance to man. There is a phrase current in certain parts of Europe that herring is king; but "King Herring" feeds upon copepods, and no copepods, no herring.

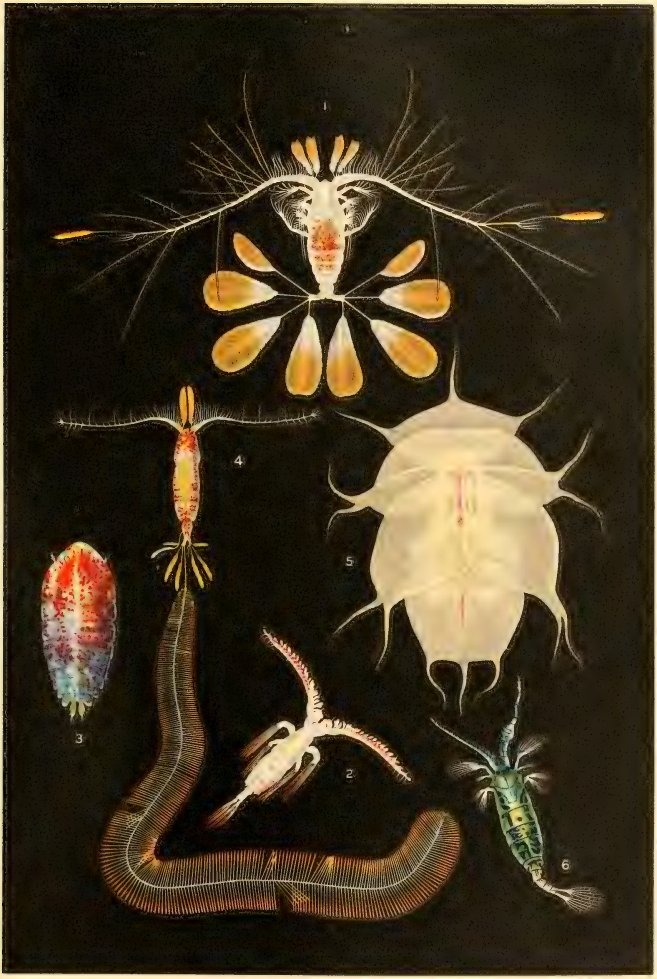
Of the hundred million pounds of fish caught annually in the Great Lakes, whitefish and lake herring form the bulk; and cladocerans and copepods constitute from sixty-three to ninety-seven per cent by volume of the food of these two kinds of fish. Like the cladocerans and the ostracods the copepods compensate for their microscopic size by their unbelievably large numbers. They multiply

more rapidly than the proverbial flies. A rough estimate of the number of individuals produced annually in a mere ten cubic meters of Baltic sea water is nine billion.

But not all copepods are the helpless victims of the appetites of other organisms. The race has predatory capacities of its own and has, moreover, made parasitism a fine art. It has displayed a genius for adapting itself to live at the expense of practically every other living thing in the sea. Any scheme of classifying copepods divides them naturally, therefore, into free-swimming and parasitic forms.

The free-swimming copepods differ from their parasitic relations as good differs from evil. James Dwight Dana, famous not only as a geologist but as a zoologist as well, described not less than twenty species of the genus *Sapphirina* (a name derived from the Latin word for sapphire), endowing each with a name—also in Latin—appropriate to its most obvious character, such as "the beautiful," "the metallic," "the variegated," "the splendent," "the scintillating," "the rainbow," "the opalescent," and so on. "Nothing," he says, "can exceed the beauty of some species, and especially the males." (Plate 39, No. 3.)

Along with color go the most bizarre shapes and bodily adornments resulting from adaptations to make flotation easy. Many free-swimming copepods are active forms, others are more or less passive floaters (with the means for such an existence), while still others are jumpers and skippers. Some of the latter are so energetic and occur in such immense numbers that they give the most startling illusion of rain at sea, although there may not be a cloud in sight above the horizon. In particular I have reference to *Anomalocera pattersoni*, a form that lives close to the surface of the sea and for which "flying fish of the copepod world" would not be an inappropriate designation. The Norwegian fishermen call them "Bla-ate" (blue bait) and hail a "shower" of them as a good sign of the approach of



Copepods: 1 and 2, *Calocalanus pavo*, female and male respectively; 3, *Sapphirina ovatolanceolata*, male; 4, *Calocalanus plumulosus*, female; 5, *Notopterophorus elatus*, female; 6, *Anomalocera patersonii*, male. Much enlarged. After Giesbrecht

the summer herring, which feeds upon them in vast numbers. Among the floating Copepoda are some of the most notable members of this subclass, long to be remembered for their splendor of form.

Pelagic copepods may first attract our attention, but they have hundreds of bottom-dwelling relatives. Even

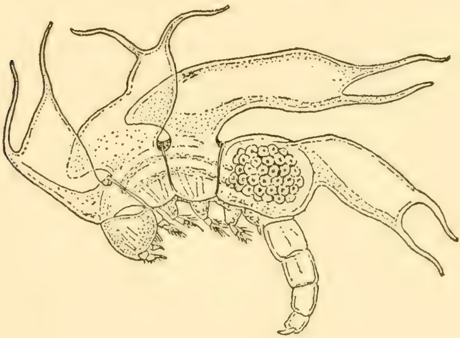


FIG. 16. A female butterfly copepod (*Notopterophorus papilio*) with eggs (x 15). Compare with Plate 39, No. 5, which is the dorsal view of a related species. After Sars

the hard-packed sandy beaches of our shores support a considerable copepod population. In a single pail of sandy water taken from a New England shore Prof. C. B. Wilson gathered 800 specimens belonging to twenty-five species of Copepoda, several of which were new to science. Marine copepods, also, occur in the abysses of the ocean at depths of 2,650 fathoms—three miles below the surface.

Of the widespread fresh-water copepods the best-known genus is *Cyclops*, so named because, like all typical copepods, it has but a single median eye in the middle of its forehead. The running water of streams seems to be more scantily populated with copepods than that of pools or

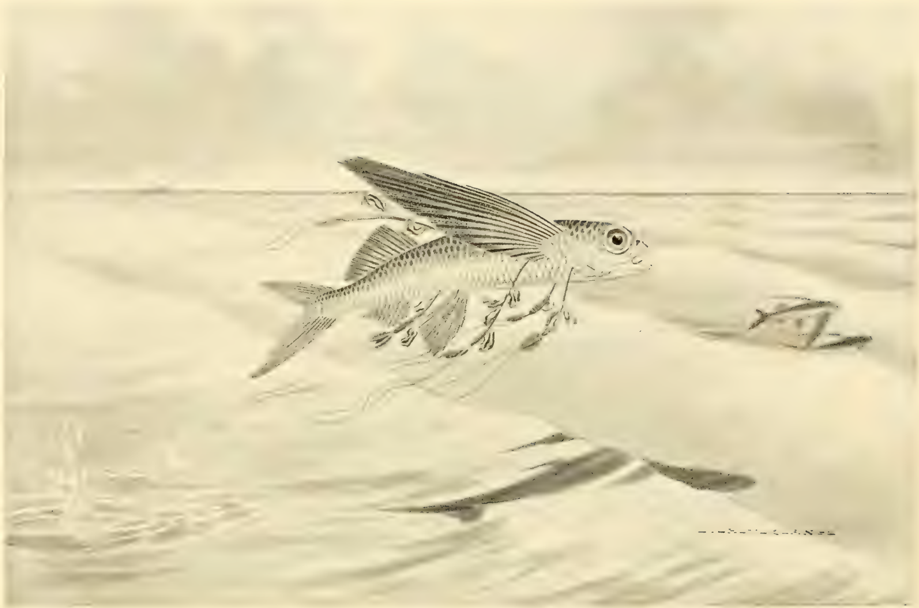
lakes. Fresh-water copepods share the common name of water-fleas with the cladocerans, the smaller phyllopods, and the ostracods; also they share with the three latter forms their varied and unusual habitats the world over. The fresh-water copepods are perennial, like weeds in the field. Some species are strictly summer forms, and others seem to thrive best in the colder parts of the year. Some cold-water copepods, like *Cyclops bicuspidatus*, are said to spend the summer months in cocoons formed of mud and other bottom materials held together by a glutinous secretion. Because of their occurrence in vast numbers in favorable situations, these fresh-water copepods, like their marine relatives, constitute a very important item in the diet of many fresh-water fish, and probably in that of the young or larval stages of most of them.

Turning to the amazing story of the parasitic copepods, we learn—as the result of Professor Wilson's extensive studies of them—that in no other group of Crustacea has parasitism led to such diversity of structure and life history. The parasitic habit of life has been adopted to a greater or less degree by many different families in the group, and every step in the transition from the more normal free-swimming type to a completely parasitic one is represented. There is scarcely a class of animals that is not adversely affected by one copepod or another, unless it be the microscopic unicellular Protozoa, which are even smaller than the smallest copepod and hence too small to support the luxury of a crustacean parasite. The modifications of structure which parasitism has effected in some species of Copepoda are so great that no one could be expected to guess their crustacean relationship. But by their larvae you shall know them; for like all good entomostracans, no matter what their later life may be, most of them leave the egg as a minute nauplius. (Fig. 17.) Normally following the nauplius and metanauplius forms (of which there may be several stages) the larva transforms into the copepodid stage, which is a precursor of the final adult

Parasitic copepods on fishes

Upper left: *Lernaeopoda* on gill of salmon. Upper right: Thirty-two individuals of *Lepeophtheirus* on fin of flounder. Lower: *Lernaeocera* on gill of whiting. After Scott. Courtesy of the Ray Society, London

PLATE 41



Copepods (*Pennella exocoeti*) and barnacles (*Conchoderma virgatum*) parasitic on a flying fish

stage. Some of the parasitic forms pass through the nauplius stages while still within the egg and hatch as a free-swimming copepodid. At this stage, the tiny animal seeks a host to which to attach itself, subsequently under-

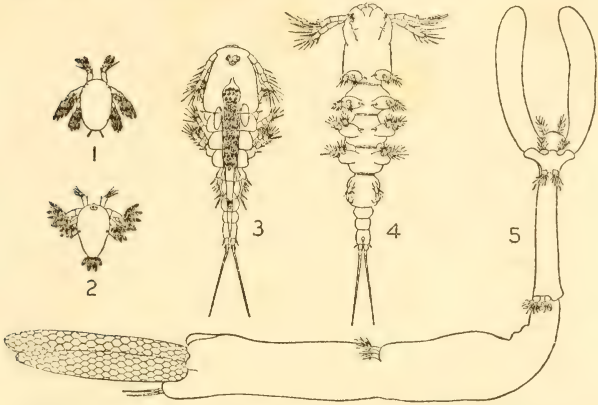


Fig. 17. Stages in the development of the parasitic copepod *Lernaea variabilis*. 1, nauplius (x 40); 2, metanauplius (x 40); 3, female fourth copepodid larva (x 35); 4, male fourth copepodid larva (x 40); 5, adult female (x 10). After Wilson

going transformation into a rather strange adult—usually little more than a feeding, reproductive mechanism for producing further parasitic copepods.

The most familiar, by name at least, of the parasitic copepods are the fish-lice, though this term is equally applicable to certain parasitic malacostracans quite far removed, carcinologically speaking, from the entomostracan fish-lice before us. One of the more thoroughly investigated genera, *Lernaea*, of not uncommon occurrence on certain tropical and temperate fresh-water fishes, will illustrate the life history of the group. The free-swimming copepodid larvae attach themselves to the gills of a

convenient fish host of the right species, and there male and female mate while still in a larval stage. Thereupon the male, his usefulness at an end, apparently dies, like the drone of the beehive. The female, on the other hand, deserts her first fish host to settle down on a second host, this time on the outside of its body instead of on the gills. Once established she becomes transformed into the adult, as we know her, of the species she represents, and becomes a permanent, fixed parasite for the rest of her natural life. For purposes of secure attachment, the sides of the cephalothorax grow out laterally as "horns," which may extend into the flesh of the host or else become firmly affixed to its scales; in either case, however, the head burrows in the tissues of the host in search of nutriment. This treatment often causes a good-sized lump or tumorous growth to develop on the host, and this may be raw and bleeding within. It has a perforation through which the hinder part of the parasite projects in order that her young shall have no difficulty in taking up a free-swimming existence when once the fertilized eggs begin to hatch. Considering that *Lernaea* is a pronounced parasite, the free-swimming larvae of the genus are exceedingly active and very tenacious of life. They are for all the world like any other entomostracan in their structure and behavior at this time of life, exhibiting characteristics which we have learned to associate with the two preceding subclasses of Entomostraca—the Ostracoda and the Branchiopoda.

All families and, in fact, all species of fishes seem to be victimized by one or another of the parasitic copepods, and a list of the hosts of the copepods in a given body of water is well nigh a catalogue of its fish population. And the poor fishes are attacked in every conceivable manner and in almost every conceivable part of their anatomy—in the mouth cavity, on the gills, and even in the nostrils, as well as within the body.

The spiracle of the gray skate harbors *Charopinus*, a

fellow full two inches long. The nostrils of the cod are the chosen home of another copepod, which evidently feeds on the mucus secreted there. As many as twenty-nine individuals have been taken from the nostrils of one cod. To still other genera the eyes of their hosts offer the one worth-while abode, and they become so embedded in these organs that only the most painstaking dissection can remove them entirely. One of these—*Phrixocephalus diversus* Wilson—burrows completely through the fish's eyeball, halting only when its head again emerges on the side opposite to that on which it entered; there it invests the outer wall of the retina with its mouth so as to draw on the rich blood supply of the network of vessels nourishing the retina. Of course, the sight in the organ attacked is forever doomed. Other species of copepods burrow into the body cavity of the host and attack the heart, liver, and other vital organs.

The largest and the most striking of the copepods, genus *Pennella*, are found as parasites on at least eight genera of fish, including the giant swordfish, the shark sucker, the gigantic ocean sunfish, and the flying fish (Plate 41). As can be seen in Figure 18, the abdomen of *Pennella* carries a series of branched featherlike processes arranged in a row on either side. These so resemble feathers in appearance that not only do they give the genus its name, for *Pennella* is the diminutive of the Latin *penna*, a feather, but the species infesting flying fish are popularly known as the "feathers" of this soaring inhabitant of the tropic seas.

Pennella, as well as some other parasitic copepods, victimizes other animals besides fish. *Pennella balaenopterae* is found in considerable numbers on the common rorqual or finner whale—one of the largest of mammals. This species may attain a length of twelve and a half inches not including the ovisacs or egg strings, which sometimes trail out behind the body of the parasite for a distance as great again. The possession of egg

strings or egg sacs, incidentally, is very often a distinctive copepod character, whether the form be marine or fresh-water, free-swimming or parasitic.

On the whale, too, is found another copepod, whose parasitism—if its habit of life can be so designated—might be difficult to demonstrate. *Balaenophilus unisetus*, in all its stages from the newly hatched nauplius to the adult form, clings in such numbers to the baleen or whalebone plates of its host as to form great yellowish patches on them. Quite unlike the free-swimming nauplii usual to other copepods, those of *Balaenophilus* are sedentary, probably with very good reason; for if a baleen-infesting copepod were free-swimming it might unwittingly leave "home and fireside"—a move tantamount to losing itself in the wide-open spaces of the high seas, since the number of baleen whales is comparatively small and since these desirable hosts cruise through a vast expanse of water at the rate, often, of twenty miles an hour. A lost or strayed copepod, therefore, would have a poor chance of finding another suitable host. And not only is the nauplius of this copepod sedentary, but the species at all stages is equipped with powerful grasping organs, which enable it to keep its place on the whalebone plates and to resist the strong current of water that must pass between the plates when the whale is in the act of straining his food. The adult female of this species may reach a length of 2.4 millimeters, while the male is somewhat smaller. To this day the only specimens of *Balaenophilus* known to science are the original lot taken in 1879 by Dr. Carl Aurivillius, the Swedish naturalist, from the baleen of the sulphur-bottom whale.

It would seem that animals that spend but a part of their lives in water are as helpless as the deep-sea dwellers to escape these widely distributed and marvelously adapted copepod pests, for in Japan the genus *Lernaea* has been found on an amphibian, the Japanese salamander. This is the only vertebrate other than fish and marine mammals known to be infested with parastic copepods.

There is no conception of *noblesse oblige* among the Copepoda and they willingly levy tribute on any convenient crustacean relative. Even the land crab of the West Indies, the big bluish-gray *Cardisoma guanhumi*, which but once a year goes down to the sea to hatch its young, supports two known species of parasitic copepods on its gills; and as many as thirty copepods have been obtained from the gills of a single crab host. These parasites, of necessity, must have their lives so beautifully attuned to that of the host that they, too, can take advantage of the crab's annual dip in the ocean to perpetuate their own kind, which will in turn infest other land crabs as they are spawning. Since this dip endures but ten days at the most, the adjustment is a most remarkable provision of nature. There can be no doubt that it exists, however; for though the crab's gill, while that animal is on the land, is moist enough to keep the copepod alive, it does not appear to be moist enough to aerate the copepod's eggs properly.

Copepods of the family Choniostomatidae are found parasitic on other crustaceans exclusively. One might call them microscopic nits. They bore a little hole in the shell of the host to obtain sustenance; and the female, at least, spends the balance of her life in complete dependence. Shrimps of several kinds, mysids, and especially amphipods, isopods, and cumaceans are all attacked by these tiny beggars.

The starfishes and their kind, collectively known as echinoderms, likewise contribute to the support of parasitic copepods. Four species of these crustaceans have been taken from three different kinds of ophiurans, as the brittle stars are technically termed. The parasites often establish themselves within the host and usually produce malformations or galls.

Parasitic copepods also prey on hard-shelled mollusks. While still in the nauplius stage they find their way into the gill tubes of the sand clam *Mya;* and they are found

in two species of mussels, in the toothsome scallops, in razor clams, and in cockle shells. *Pennella* larvae have been found on the gills of the cuttlefish—a mollusk with an internal shell; nor have the nudibranchs—sluglike mollusks without shells—escaped giving food and shelter to uninvited copepod guests.

Degeneration or specialization among parasitic copepods is carried to the extreme in those forms that live on certain marine annelid worms and also in those that live on certain other crustaceans. In the best known of these highly specialized forms the adult female is entirely without appendages and is attached by a tubular process which ramifies within the body of the host. The males are also limbless; and, rather remarkably, they never escape the last larval stage—in this case the first copepodid stage—spending their lives attached to the female of their species (several males to each female).

Of the other lesser known animals of the sea, those commonly parasitized by copepods are the jellyfish and the soft corals (sea pens and other alcyonarians). Temporary- or semi-parasitic copepod forms have been found on sponges, also. And one strange species seems to live in and prey upon a marine plant, causing a gall-like malformation on its fronds.

We have spoken of the magnificently colored free-swimming males of the genus *Sapphirina*. The wives of these gallant cavaliers are generally quite colorless creatures which devote a considerable part of their lives to raising one brood after another within the "glass houses" of the salps which they parasitize.

The more one delves into the relations of animals to one another, the more often one finds illustrated Dean Swift's oft misquoted doggerel:

> So Nat'ralists observe, a Flea
> Hath smaller Fleas that on him prey.
> And these have smaller Fleas to bite 'em,
> And so proceed *ad infinitum*.

Copepods are no exception. *Pennella,* which parasitizes the whale, is, in turn, the unwilling support of a peculiar barnacle, *Conchoderma virgatum.* The barnacle in this case is a passive parasite, making use of but not actually subsisting on its host. It merely adds to the sum total of the

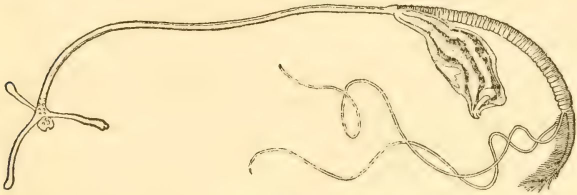


FIG. 18. A parasitic copepod (*Pennella balaenopterae*) taken from a finner whale, and itself carrying the barnacle *Conchoderma.* After Turner

burdens which the copepod is called upon to carry through its marine existence. Dr. C. B. Wilson tells of a *Pennella* four inches in length to which were attached eighteen *Conchoderma,* the latter forming a mass many times the size of the copepod. Dr. Wilson remarks that the *Pennella* exemplify the fact that one parasite often serves as the host for another. Attached to the outside of their host, where they catch all that floats in the water, the *Pennella* very quickly become covered with algae, ciliate infusoria, hydroids, and even barnacles, as noted above. Seaweeds, too, find their place on these copepod parasites. Though troublesome to the parasite on account of their weight and bulk, these added organisms are not to be considered superparasites, for they do not feed on the copepods to which they attach themselves.

The most remarkable case of multiple parasitism is one reported by Dr. C. Perez. A Mediterranean bivalve, *Spondylus,* like many of its kind, often harbors a pinnotherid crab, parasitic to the extent, at least, of feeding on the foodstuffs collected by the bivalve for its own con-

sumption. Dr. Perez found one of these crabs that was itself infested with a rhizocephalid (of barnacle kinship), and the rhizocephalid in its turn was being preyed upon by an ectoparasitic isopod of the genus *Eumetor*. Isopods on the rhizocephalid *Sacculina* as secondary parasites have been noted before; but a tertiary parasitic relation of the sort just recounted is quite unusual, though not unreasonable.

But *Sacculina purpurea* presents a much more astounding phenomenon. This rhizocephalid is not uncommon as a parasite on a certain South American hermit crab; and its roots are made use of by other parasites, which, to quote Stebbing, "take up their abode beneath the *Sacculina* and cause it to die away by intercepting the nourishment conveyed by its roots; and when the *Sacculina* itself is dead its roots continue to flourish and abound at the expense of the hermit and for the benefit of the besieging *Bopyrus* [a genus of the parasitic isopods]."

In all this gamut of parasites there is still one more group of copepods, or, rather, "near-copepods" to be mentioned. These are the "fish-lice" in the true sense of the term, and in the form of the genus *Argulus* (Fig. 19), they have been met with on frequent occasions in goldfish aquariums. The argulids differ from all true copepods in possessing paired compound eyes. They feed on the blood of their host, and those that infest migratory fish are strongly suspected of being able to change with their host from salt to fresh water or the reverse. Another peculiarity of the argulids is that they do not carry their eggs around with them, as do regular copepods, but deposit them on some favorable surface on the bottom, or, if in aquariums, sometimes on the glass sides. If an argulid does not succeed in finding a host of the species on which it is specifically parasitic, it has been known to live on almost any other fish, and even on tadpoles. Naturally, a change is made to its natural host at the first

opportunity. Rather wonderful, this sense of host recognition among animals of this low degree, whatever its explanation may be.

The argulids are ready swimmers, but progress rather peculiarly—by somersaulting through the water, as it were. An external parasite needs an efficient means of

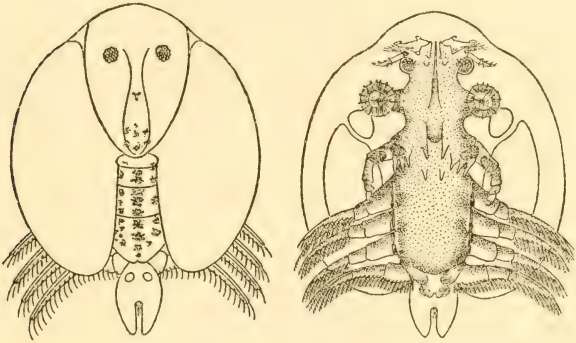


Fig. 19. A parasitic copepod (*Argulus trilineata*) sometimes found on goldfish. Dorsal and ventral views of a female. Note in the ventral view suckers and hooks on the antennae by which she attaches herself to the fish (x 9). After Wilson

anchorage. In the argulids, the anterior maxillipeds are modified into powerful muscular sucking disks; and "by a walking motion of these same disks they scuttle about over the fish's skin so long as it remains moist." The suckers lose their adhesive power on a dry surface. Further to keep from slipping backward off the fish as it darts through the water the argulid's antennae are provided with stout hooks, spines, and bristles, which at the slightest backward movement grip fast to the skin of the fish. The greater the speed and the water pressure, the tighter the argulids stick.

Cirripedia

The subclass Cirripedia gets its name from the cirruslike or feathery feet of its better known representatives—the barnacles, order Thoracica. The other order—included in the subclass—Rhizocephala is comprised of parasitic degenerates which no one would recognize as Crustacea. Huxley has aptly described a barnacle as an essentially shrimplike form that has become attached by the head to some submerged surface; has incased itself in an armor of stout plates, often fused together; and kicks food into its mouth by means of its filamentous, feathery-appearing feet, which have become characteristically modified for the purpose.

Barnacles fall quite naturally into two categories or suborders—the sessile and the stalked (Fig. 20).

Sessile barnacles are commonly called "acorn shells" or "acorn barnacles" because of their supposed resemblance to the acorn. The soft body of the animal is surrounded by an immovable shelly wall or palisade of plates which grows attached to some means of support, such as stones, piling, ships' bottoms, or the bodies of other animals. The free end of the shell is closed by a four-jointed lid known as an operculum. The technical name of the suborder, Operculata, is derived from this structure. The calcareous covering or wall of the barnacle serves it, in its more or less helpless condition of fixation, as a protection from all aggressors not strong enough to crush it.

The barnacles of the second suborder, the Pedunculata, are likewise attached to a support from which they never escape. The body, however, with its inclosing valves, is elevated on a stalk, or peduncle, which may be fleshy, leathery, or scaly. The valves of the Pedunculata are usually thinner than those of the Operculata and are movably articulated with one another.

The members of the Pedunculata may vary quite widely in appearance and habitat. In some the body is

heavily armored with calcareous plates, while in others the plates are incompletely calcified or present only as vestiges. Some are fixed immovably in one spot, while others are attached to large pelagic medusae (jellyfish)

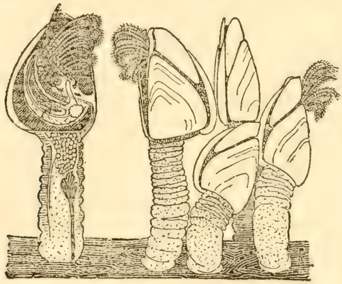


FIG. 20. Stalked and sessile barnacles (*Lepas* and *Balanus*). The stalked barnacle on the left is shown in longitudinal section. The cement gland by which the barnacle attaches itself is seen in the lower half of its fleshy stalk

and are limited in distribution only by the range of their hosts.

But how is one to know that a barnacle is a crustacean? For many, many years barnacles were considered as shellfish and mollusks, along with clams, oysters, snails, mussels, and the like. However, the clue to their crus-

tacean nature lies in their growth stages (Fig. 21), as does that of the parasitic copepods we have just been considering. It is scarcely believable that the young barnacle emerges from the egg as a nauplius, like any other entomostracan; but with few exceptions it does. The nauplius

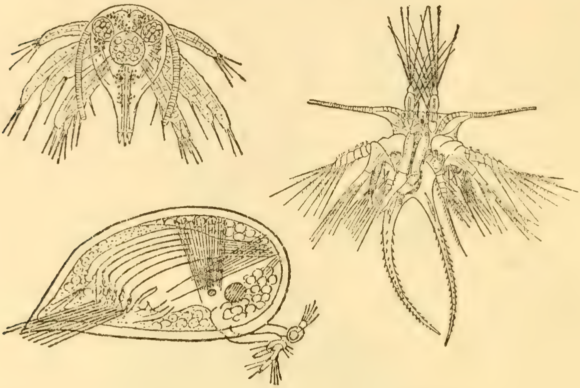


FIG. 21. Three larval stages of a stalked barnacle (*Lepas*). Upper left, newly hatched nauplius. Right, metanauplius. Lower left, cypris stage. All much enlarged. After Groom and Claus

of the barnacle, in structure, appearance, and behavior, is scarcely to be distinguished from that of any other entomostracan. It progresses through a number of stages with little change in form until it reaches a definite metanauplius stage. This lasts but a short time and at the next molt the young barnacle transforms into a cypris-stage, so called because of the bivalved shell with which the cirriped is provided in this stage and which gives it a resemblance to the real *Cypris*, an ostracod. However, as the larva possesses already the full complement of appendages of the adult barnacle, it is in all essentials a free-

swimming cirriped. During this brief period it is free to leave home and seek its own fortune, which it does by finding a suitable place of settlement. To this it attaches itself by means of the cement glands with which it is provided, and goes about the business of being a recognizable barnacle for the rest of its natural life. The free-swimming larval stages permit the otherwise sessile, sedentary barnacles to scatter to the four corners of the marine world. Some are found only in very restricted localities; while others, like those that are seen on the hulls of ships, range the Seven Seas.

Barnacles of the genus *Chelonobia* are found on the shells of sea turtles, a location for which they are structurally well adapted. Others are found attached only to whales. Mr. Ira Cornwall has observed that these species have accommodated themselves most wonderfully to the 10,000-mile voyages indulged in by their mighty hosts, during which the whales journey from their breeding ground in the equatorial seas to their summer feeding grounds in the shadow of the poles. To cope with the extremes of environment confronting the animals in the course of the whales' migration—especially the sojourn in tropic seas—certain of the whale barnacles of the genus *Coronula* possess the largest and most highly developed gills, or branchiae, of any cirripeds known. As Mr. Cornwall explains, "It is well known that the warm water of the tropical seas contains less oxygen than the cooler water of the northern and southern oceans; also the increase of temperature causes an increase of the rate of metabolism, and a consequent greater demand for oxygen. The combination of these two factors would explain the great development of the branchiae of the barnacles." He also remarks that this would account for the large gills of another crustacean found on whales, "the amphipod *Paracyamus boopis*, the common 'whale louse,' which is found in thousands on and among the barnacles of the whales."

And how differently do the several species of whale barnacles attach themselves to their host! *Coronula reginae*, with very few exceptions, is "found only on the lips and the front edge of the flippers"; *Coronula diadema* in heavy masses on the throat and corrugated belly. The latter "is not embedded in the [whale's] skin at any stage of its development, while *C. reginae* commences its growth below the surface, only the hood projecting above the level of the skin. As the shell grows, the skin is forced back till about a third of the shell is exposed. . . . *C. diadema* is barrel-shaped, and its station brings its opening nearly at right angles to the line of motion of the whale. *C. reginae* is much depressed, and it is situated in such a way as to bring its opening facing forward." Another peculiar barnacle, also found on whales, is so attached to the flippers and flukes that its opening faces backward when the whale is in motion. This barnacle has been reported as occurring on porpoises also. The rarest of the whale barnacles in American collections is a small, tubular, storied-looking affair, *Tubicinella major*. It is found on the upper jaw, on the forehead, and over the eye of the southern right whale. *Stomatolepas*, as the name indicates, is found embedded in the mucous membrane of the gullet of sea turtles. *Platylepas* lives embedded in the skin of turtles and in that of manatees, sea snakes, and fishes as well.

In the course of a study of the bottoms of some 250 ships calling at Atlantic coast ports of the United States, not less than sixteen species of barnacles were enumerated. Barnacles are among the organisms that contribute most toward the fouling of ships; and they have the added disadvantage, from the mariner's standpoint, that their shells remain even after they die, and can be removed only when the vessel is docked and scraped. Softer animals and seaweeds tend to die and rot off when moved from warm to cold or from fresh to salt water or *vice versa*. Fouling may diminish the speed of a vessel as much as

fifty per cent and increase the time required for a voyage from ten to fifty per cent; it causes an increase of fuel consumption, with corresponding wear and tear on the machinery, and necessitates frequent docking. Docking and scraping is the only sure method of keeping down underwater growths on vessels. It costs approximately $100,000 to dry-dock, clean, and paint such a vessel as the *Leviathan* or the *Majestic*, each of which has more than an acre of surface under water. The barnacle proved to be the principal fouling organism in 116 out of 217 vessels, and the second most important factor in 36 others. Crustaceans do take their toll of ships and shippers. According to the United States Bureau of Fisheries, heavily fouled ships frequently carry more than 100 tons of fouling material and occasionally more than 300 tons. It is conservatively estimated that the annual cost of fouling to the shipping industry of our country is in excess of $100,000,000.

But barnacles have their uses as well as their drawbacks from man's point of view. In Chile, where a common species grows to a prodigious size (for a barnacle)—nine inches in length and several inches across—the meat of this shrimp relative is an important article of food. It is considered quite a delicacy and is much sought after as an ingredient of soups and chowders. The flavor—all its own—of this barnacle soup is equal to that of the best clam chowder, while the flesh is more palatable than clam meat. In Japan a small species of barnacle is cultivated on stakes, from which it is scraped off and used as fertilizer.

One of the strangest phenomena about some species of barnacles is that the males are dwarfs. The great majority of Cirripedia are hermaphroditic; but two genera, *Scalpellum* and *Ibla*, have dwarf males comparable to those known in some deep-sea fishes and in certain other crustaceans. These males are often without appreciable structure, and probably all are short-lived. Some of them are attached to hermaphroditic individuals and so seem

to be "complemental males," as apparently they are not altogether necessary in the perpetuation of the species. When attached to purely female individuals, however, the dwarf males must be of some use. Such males are structurally more developed—have something of an alimentary tract—and so able to carry on a life of greater duration, but scarcely of greater independence than the "complemental males," as they are confined to the mantle cavity of the female and dependent on her bounty for existence. The less developed dwarf males lack both the means of acquiring sustenance and the organs to assimilate it. They suggest at once the May flies, the males of which have neither mouth, stomach, nor other means of taking nourishment. They exist solely for the purpose of perpetuating the species, and when that vital function is discharged, they pay the supreme sacrifice. So it is, no doubt, with the dwarf males of barnacles, which do not, and perhaps can not, feed even if they would.

Before leaving the barnacles some mention needs to be made of their "poor" relations—the rhizocephalids (order Rhizocephala), which have become such abject parasites as not to be recognizable as barnacles, or even as crustaceans, if it were not for their life history. The rhizocephalids prey on other crustaceans only. Found parasitic almost exclusively on decapod Crustacea, the full-grown rhizocephalid appears superficially little more than a tumorous growth attached to the underside of the abdomen of the host.

An adult rhizocephalid is a mere envelope of thin chitin: it shows no trace of segmentation, appendages, or even an alimentary tract. It carries a visceral mass and reproductive organs (usually male and female in the one animal), and is nourished by a threadlike absorptive root system which penetrates the body of its host in all directions. Its effect on male decapod hosts is profound, resulting in an apparent unsexing. The male crabs, par-

PLATE 42

Heavy accumulations of barnacles and other marine organisms fouling a ship's propeller. After Visscher.
Courtesy of the Bureau of Fisheries

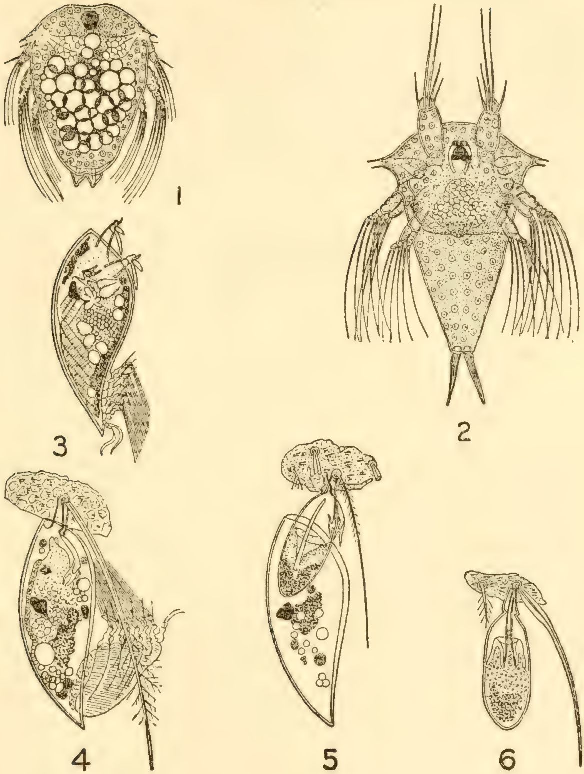


Fig. 22. Stages in the development of the parasitic rhizocephalid *Sacculina carcini*. 1, nauplius newly hatched; 2, after the first molt; 3, free-swimming cypris stage; 4, cypris stage attached to a seta of the host crab; 5, larva still attached and in act of casting cypris shell; "dart" almost formed; 6, dart beginning to penetrate shell of host at base of a seta. All much enlarged. After Delage

ticularly, when infested with rhizocephalids, tend to take on the secondary female characters of their kind, most noticeably the broader abdomen of the female (Fig. 23).

But stranger than its structure or than its effect on its host's structure is the life history of the rhizocephalid (Fig. 22). Hatching out usually as a nauplius and transforming into a cypris stage, like any normal barnacle, it

FIG. 23. Adult rhizocephalids parasitic on the abdomen of a hermit crab, a burrowing shrimp, and a crab. Twenty-two individuals of the sausage-shaped species *Peltogaster socialis* have been found on a single hermit crab. After Smith

settles down usually on some decapod host. It is selective, however, in its choice of hosts. Some forms will infest only one species of crustacean. The larva settles down on the host wherever it can find lodgment, though, seldom, if ever, on the abdomen, where the adult rhizocephalid is found. Probably burrowing downward at the base of a hair or seta through the integument of a newly molted decapod, the larva undergoes some remarkable changes in order to work its way through the body of its host and finally, in an unexplained manner, to find lodgment above the abdominal wall. Here it begins to send out rootlike processes, which cause degeneration of the body wall of the host. An opening is formed through which, at the time of one of the molts of the host, the mass of the rhizocephalid takes up its accustomed external position. The parasite then proceeds to suck the vital fluids of the crustacean which carries it and to produce new individuals of its kind, which, in their turn, will infest other crustaceans.

MALACOSTRACA

We have now returned to our starting point—the subclass Malacostraca, which contains the lobsters, crabs, and shrimps. It contains also many other kinds of crustaceans—as many, in fact, as all the other subclasses of Crustacea put together, so that we may expect to find quite a number of strange forms in this immediate family circle of the familiar decapods. But we have at least one reliable touchstone by which to test any eu- or true malacostracan. That is the possession of nineteen body segments. In the entire subclass Malacostraca, only one restricted group—the Leptostraca—is an exception to the "nineteen-segment" rule. All the other groups conform.

SERIES LEPTOSTRACA

Between the Entomostraca (the group at whose peak stand the barnacles) and the Eumalacostraca there occurs a small, inconspicuous group of crustaceans which possesses some characters of each of the other two. This intermediate group has been classified as the "series" Leptostraca, in contradistinction to the "series" Eumalacostraca (true Malacostraca), which includes all the rest of the subclass to which both belong. A good malacostracan from head to toe and representative of the Leptostraca is *Nebalia bipes* (Fig. 24), which fails of being a eumalacostracan only by the tip of its tail, so to speak. For in its tail lies its distinguishing character, and the evidence of its relationship to the lower orders of Crustacea. While in all true Malacostraca the abdomen is made up of six somites, in the Leptostraca it includes seven, and the telson or tailpiece is forked in a manner reminiscent of the Branchiopoda. Thus the total number of somites in the Leptostraca is twenty instead of nineteen; and so this group tends, however slightly, toward the variability in number of somites that is also a character of the Entomostraca. The carapace of the Leptostraca likewise differs

slightly from that of all the true Malacostraca that possess such a thing, for it is hinged on the mid-dorsal line and is provided with an adductor muscle to draw the two halves together. The rostrum is hinged and movable and when

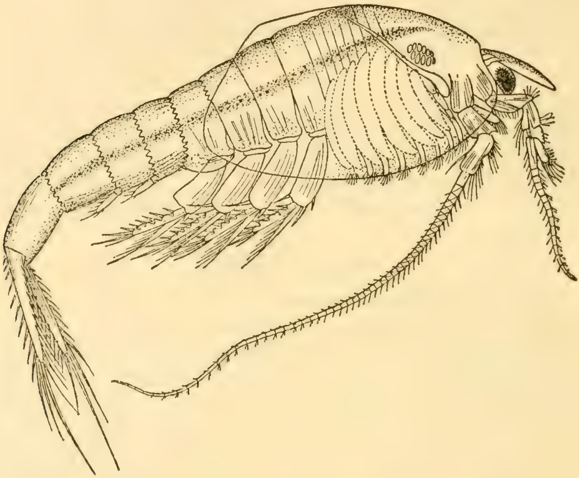


FIG. 24. Female *Nebalia bipes*, showing the forked telson and movable rostrum (x 11). Adapted from Sars

bent down closes the anterior gape of the carapace for all the world like the snap lid on a sirup pot. No doubt this novel shield functions at times to better protect the ova, which are carried by the female in a sort of loose basket formed by the thoracic legs. The young are carried thus until they in great measure resemble the adults.

The Leptostraca are wholly without fresh-water representatives so far as known. Though mostly shallow-water forms, at least one species, a blind one, *Nebalia typhlops*, ranges the intermediate depths of the ocean, from 500 to

750 fathoms down, where it feeds on smaller organisms. Except for *N. typhlops*, the Leptostraca are largely, if not wholly, detritus feeders—stirring up the sea bottom in search of food—and at times scavengers; for a favorite way of securing them in the Dry Tortugas (Florida) is by putting out partly cleaned lobster shells as bait, which as soon as the adhering flesh begins to decay literally swarm with *Nebalia*. Temperature seems to affect but little their life processes. Most Leptostraca measure between three-sixteenths and three-quarters of an inch in length, but the giant among them, *Nebaliopsis typica*, measures more than an inch and a half.

SERIES EUMALACOSTRACA

The "series" of true malacostracans, including as it does the more highly developed and to us the better known and larger crustaceans, comprises ten orders, which seem to fall quite naturally into four major divisions.

Division Syncarida

The most simply organized and most generalized in structure of the true Malacostraca are the syncarid Anaspidacea. This order has the further distinction of comprising fewer individuals and fewer species than any other order of Crustacea except the newly created order Thermosbaenacea, which has but a single representative. Anaspidacea is made up of a bare half-dozen species, divided among four genera. Three species are confined to the antipodes, and three are restricted to the subterranean waters of central Europe. The largest, *Anaspides tasmaniae* (Fig. 25), grows to be one and a half inches in length and is found only in the mountain lakes and streams of the southern and western parts of Tasmania, at elevations ranging from 2,000 to 4,000 feet. A prime condition of its occurrence is ice-cold water of absolute clarity.

Although a very long way from Australia, Europe, long before the discovery of *Anaspides* in the newer country, had known an obscure little syncarid crustacean, *Bathynella natans*, described in 1882 by Vejdovsky from a well

FIG. 25. *Anaspides tasmaniae*, one of the simplest of the malacostracans, on a lake bottom. Black spots in lower right are eggs. Adapted from various authors

at Prague, Czechoslovakia. This well has long since ceased to exist. Not until three decades later, 1913, was the species rediscovered. Then it was found in a spring at Basel, Switzerland, which also, like the well at Prague, subsequently became filled in. After that, at intervals of a few years, the species was noted in other wells at Basel and in some Serbian caves; and as late as October, 1925, it was found in the water mains of the town of Oefingen, Germany. Still more recently another syncarid, as yet undescribed, has been reported from a cavern puddle at Kwala Lumpur, Malacca, Straits Settlements. The

bathynellids are completely subterranean in their habits, and as completely lacking in eyes. Occasionally they may swim short stretches; but most of the time they spend crawling over the bottom, carefully feeling for the microscopic, unicellular rhizopod protozoans upon which they feed.

Why do these minute European crustaceans find their nearest relatives in far-off Tasmania and Australia? That is one of the many mysteries of zoology. That they are archaic forms is suggested by the habit which the female *Anaspides* has of depositing her eggs instead of carrying them, as do nearly all Malacostraca.

Division Peracarida

Order Mysidacea

Of the six orders comprising the division Peracarida, the first, Mysidacea, divides honors with the copepods and ostracods as a food for marine animals in all the oceans and in many of the lakes and smaller bodies of water in the

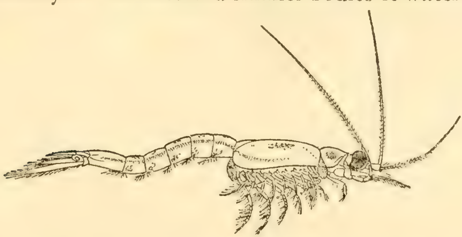


Fig. 26. A fresh-water opossum shrimp, *Mysis relicta*. The brood pouch shows between the thoracic feet. After Sars

Northern Hemisphere. In our own Great Lakes *Mysis relicta* forms from eighty to a hundred per cent of the food of the chub, a commercially important fish. The mysids are small but prolific, occurring in incalculable numbers.

"Opossum shrimp" is the vernacular name of the order

Mysidacea, inspired by the brood pouch (Fig. 26), formed by specially developed plates on the inner sides of the thoracic feet of the female. In this the eggs are hatched and the young sheltered until they can strike out for themselves with a full complement of well-developed appendages. The possession of such an incubative arrangement by the female is one of the distinguishing characters shared in common by all good peracaridans.

The Mysidacea, with the exception of a few rare forms, are without gills as we know them in the higher Crustacea, and even in these exceptional forms the gills are but rudimentary. Furthermore, the mysidacean carapace fails to unite dorsally with at least the last four thoracic somites. These and other facts have dissolved the former union in classification of this order with the order Euphausiacea, which was based on the similarity of appearance

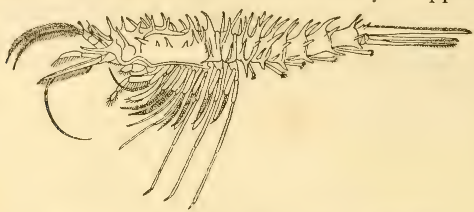


FIG. 27. A spiny deep-sea mysid (*Ceratomysis spinosa*) from 782 fathoms. After Faxon

and the characteristic development of the two-branched thoracic appendages in the two orders. Because of this common character, these two otherwise diverse orders were at one time classed together as the schizopod (split-foot) crustaceans.

The filamentous schizopods, or split feet, of the mysids are their means of locomotion and respiration; and they also produce a current in the water which wafts and drives the finer particles of food and detritus within reach of the mouth and its accessory appendages.

PLATE 43

A community of opossum shrimp (*Mysis relicta*), cladocerans (including *Daphnia pulex*), and copepods (including *Diaptomus*) from the depths of Lake Erie. Courtesy of the Buffalo Museum of Science

Mysids seem never to have become parasites, though they themselves are much plagued by isopods, which seem to leave untouched scarcely any group of marine animals whatsoever except such as are too small to furnish them a foothold or nourishment. Protozoan colonies have also been found infesting certain species of mysids. Subterranean mysids are known, one from a grotto in Madagascar, and another from Italian caves. One is even said to be commensal in the shell of a hermit crab.

ORDER THERMOSBAENACEA

This is a newly recognized order of Crustacea, proposed since the first draft of this paper was written, an apt reminder that the day of carcinological discoveries is not yet past and that there is still a very fruitful field awaiting investigation by the student and the explorer.

Thermosbaena mirabilis Monod (Fig. 28) was first collected in 1923, from a shallow hot spring in the vicinity

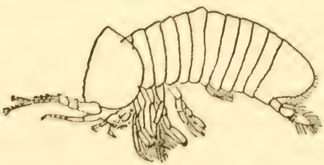


FIG. 28. *Thermosbaena mirabilis* from a hot spring near Tunis (x 15). After Monod

of the ruins of an old Roman bath near Tunis (North Africa). So strange was it and so different from all other known crustaceans that not until 1927 was a place found for it in the classificatory scheme. That place was the new order, Thermosbaenacea, lying close to the Mysidacea.

So small is the animal—two to three millimeters long—that it was at first thought to be a larva or some other juvenile form of an unknown crustacean. The body of

Thermosbaena is short and stubby, and the body regions are scarcely to be distinguished one from another without close examination. No trace of eyes or eye stalks has been found, and all the appendages are on quite a simplified or primitive plan. The mature female has a functional marsupium for sheltering the developing eggs.

The temperature of the hot springs in which *Thermosbaena* was found reaches 112° Fahrenheit. In these calorific surroundings it never swims, but crawls about on the shaded rocky walls of the spring, no doubt feeding on the only other organic life found in these waters—a species of blue-green alga which thickly coats the sides of the spring.

Order Cumacea

Third among the orders of the division Peracarida are "some little wonders and queer blunders," the Cumacea, so odd and characteristic of build—and, one is apt to feel, of personality—that once you have made the acquaintance of one or two of them you will forever after be able to recognize them in any gathering of Crustacea. With a carapace that is apparently too large for them (yet fails to protect the whole of the thorax) and a slender, feeble-looking abdomen that seems much too small, their little misshapen bodies are quite unforgettable. But nature has her plans and purposes, though most of them are yet unknown to us. What strikes us as a seeming lack of balance between the fore and hinder parts of the body is no doubt the most efficient combination that could be contrived to facilitate plowing through the mud and detritus in which the cumacean lives and feeds. We do know that the abdomen is most freely movable. The animal can reach all parts of his body with the caudal fork. In spite of his messy surroundings he is a cleanly little beggar, forever furbishing up one or another part of his external anatomy with his mobile tail, giving special attention to the food-getting appendages, which need frequent cleansing to work at full efficiency.

Small and inconspicuous as these retiring burrowers are, they sometimes occur in such vast numbers as to become an important source of food for fishes. On such occasions the males of a number of species tend to swarm at the sur-

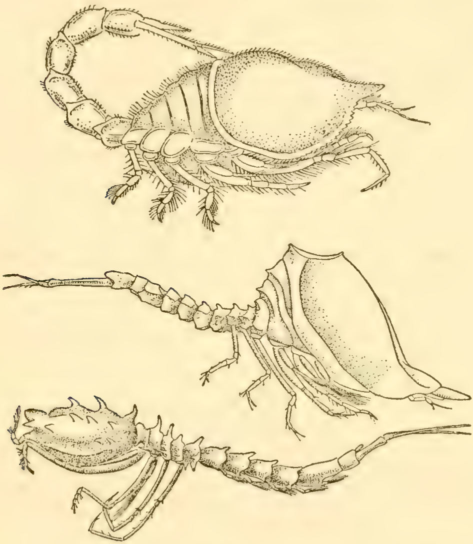


FIG. 29. Representative Cumacea. Upper, the giant *Diastylis goodsiri*, cleaning carapace with the tip of its tail (x 2). Middle, *Ceratocuma horrida*, adult male (x 5). Lower, *Campylaspis vitrea*, young female (x 5). After Sars and Calman

face, especially at night. The male is by far the more active sex and is better provided with pleopods than the female and so better fitted for swimming.

Professor Sars says that by far the greater number of species are pronounced deep-water forms, descending to

the greatest depths explored. Cumacea are found in every part of the ocean, and as far north as deep-water exploration has been instituted these peculiar Crustacea have been found to be plentiful. Indeed, in the Arctic Ocean they seem to reach their maximum of development, the huge *Diastylis goodsiri* (Fig. 29) being more than an inch in length.

A further peculiarity of this order noticeable enough to merit comment is its sessile eyes, which are drawn so closely together that they merge into one, giving the Cumacea the cyclopean appearance we had noticed among the Entomostraca.

Order Tanaidacea

Introductory, as it were, to the two final orders comprising the peracarids, we have a small yet well-marked group that are isopods in all but name, the Tanaidacea (Fig. 30). The chief character separating this order from

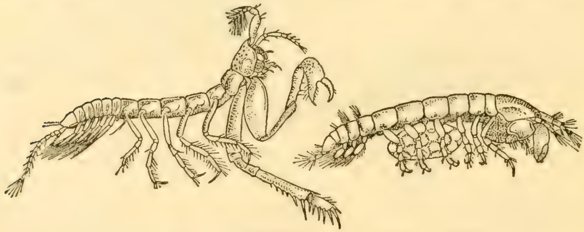


Fig. 30. Tanaids. *Sphyrapus anomalus*, male, and *Tanais tomentosus*, female (x 8), carrying eggs. After Sars

the isopods is the possession of a carapace which coalesces dorsally with the first two thoracic somites, overhanging laterally to form a branchial cavity on either side. Their eyes are a compromise between the stalk- and the sessile-eyed peracarids, inasmuch as those species in which the eyes are not wanting altogether usually have them on

little immovable processes on the head, which seem to be analogous with the ocular peduncles of the mysids.

Most of the Tanaidacea are quite minute, about a sixteenth of an inch long. Not much is known of their mode of life, but certain of them live in the mud of the littoral zone or hide away among algae, hydroids, and the like. Not all restrict themselves to shallow water, for some have been taken in the North Pacific from depths exceeding 2,050 fathoms. Certain bottom-dwelling tanaids may spin themselves little tangles of thread, within which to conceal themselves, or else fabricate a tube from their secretions, outwardly incrusting it with bottom materials or plant débris for protection. An American species, *Tanais robustus*, has, I think, the most peculiar place of abode of all the members of the tribe. It was found by its discoverer "inhabiting minute tubes in the crevices between the scales of a turtle's (*Thalassochelys caretta*) carapace."

Orders Isopoda and Amphipoda

For the first time since we took leave of the barnacles we meet crustaceans of which most of us have probably heard before; namely the Isopoda (to which belong the better-known wood-lice, or pill-bugs, found under stones in damp places) and the Amphipoda (which include the sand-hoppers, or sand-fleas, with which all visitors to the sea-shore are familiar). Both orders contain, in addition, many salt- and fresh-water forms which are not so well known.

But how is one to tell an amphipod from an isopod? The two are so much alike and so much akin that only a combination of rather detailed characters serves as a sure means of distinguishing them. For a superficial—though by no means universal—rule, one might say that the isopods are depressed, that is, flattened from above and below, whereas the amphipods are compressed—flattened from side to side. Also, isopods generally lack claws, whereas all amphipods have them.

In alluding to the amphipods, Stebbing referred to them as the "many twinkling feet." To examine their many and diverse appendages is to discover that they carry about with them almost as many tools as the proverbial plumber. In one and the same animal the different appendages are adapted to such various uses as feeling, biting, culling, holding, back brushing, shoe polishing, swimming, jumping and what not.

"Among the Amphipoda," to quote Dr. Stebbing again, "there are a few species armed with strictly defensive spines, but otherwise they are of all the Malacostraca the most absolutely and universally peaceable towards mankind, never inflicting upon him any personal injury whatever." The same might be said, also, of the amphipods' attitude toward animals other than man. They are primarily the most efficient scavengers of sea and shore, the multiplicity of them rendering them of more service in clearing up organic débris on all the world's shores than any other animals, even those much larger than themselves.

Perhaps the only great harm that can be charged to amphipods is that of destroying wooden harbor works. One species, *Chelura terebrans*, belongs to the great triumvirate of animals most destructive to wood immersed in salt water, the other two members of which are the molluscan shipworms and certain of the isopods, notably *Limnoria lignorum*. The amphipods are ever so much more preyed upon than preying, and few among them—like *Cyamus*, the whale louse—can be classed as at all parasitic. They form the bulk of the food of many animals, particularly fish, and several of the abundant pelagic species are said to form part of the crustacean diet of whales.

Quite otherwise is it with the isopods. Many species are free-swimming scavengers like the amphipods; but no end of them are degenerate parasites, lacking face and figure to such an extent that they can scarce be distinguished

from the most depraved rhizocephalid except by the locality of their attack upon the host species and by some minute but peculiar points of their internal anatomy. I refer especially to the bopyrids (Fig. 31), which are a great plague to other and higher crustaceans; for they take

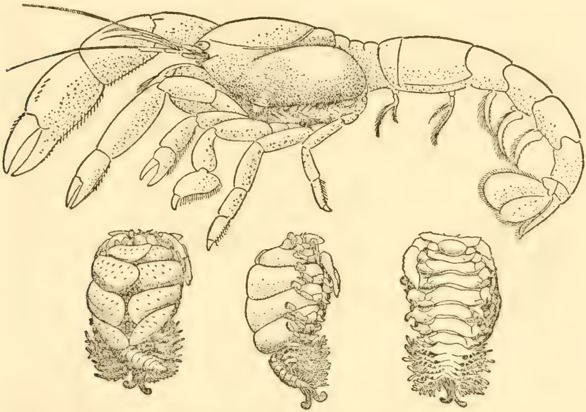


FIG. 31. A degenerate isopod, *Ione thoracica*. Above, a female with a smaller male attached parasitizing the gill chamber of a burrowing shrimp, *Callianassa*. Below, ventral, lateral, and dorsal views of the female (x 4) with the small male in normal position. After Bonnier

their seats upon the gills of the shrimp or crab attacked and cause there a characteristic and readily recognized malformation. As already mentioned in connection with other parasitic crustaceans which prey on members of their class higher in the scale than they, these isopod parasites are themselves parasitized. Also, in the order Isopoda, as in some of the parasitic barnacles and copepods, we find repeated the phenomenon of dwarf males.

Many isopods without such characteristic degeneration of form are ill-natured and are vicious enemies of fish.

The cymothoids, for example, attach themselves to the sides of their unwilling hosts or find a foothold in their mouth cavities (Fig. 32). They must be pain-causing guests, for it is not safe to detach one—no matter how

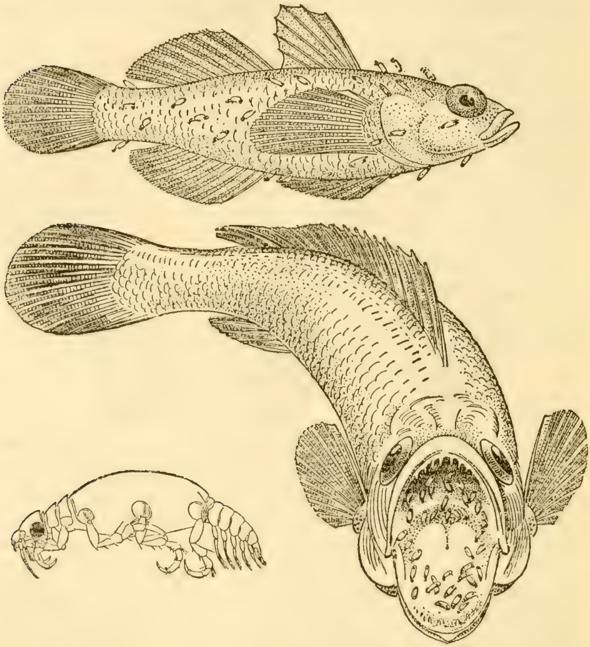
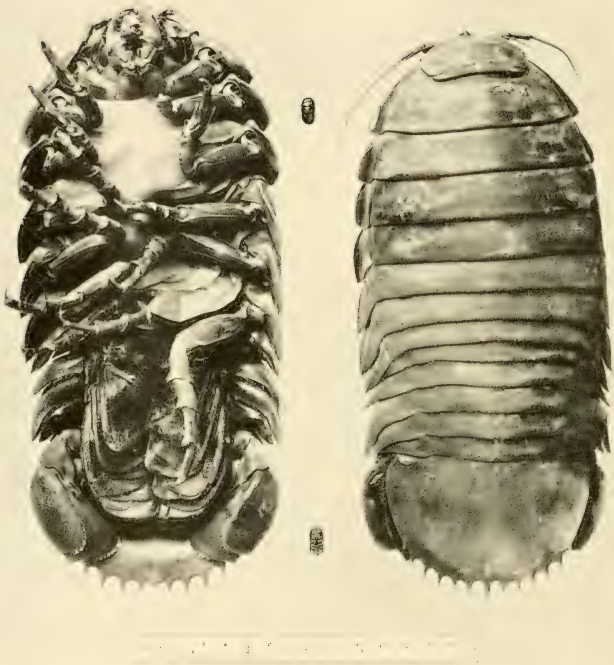


FIG. 32. Larvae of the isopod *Paragnathia formica* parasitizing the skin of a goby and the mouth of a connor. Lower left, an individual larva (x 10). This species is parasitic only in its young stages. Adapted from Monod

small—from its host with the bare hand. There have come to us a number of reports of painful "bites" that cymothoids have inflicted on the unwary by clamping

PLATE 44

A female isopod (*Arcturus baffini*) of Greenland, whose antennae serve as a perch for her growing young (slightly enlarged)



The largest known species of isopod (*Bathynomus giganteus*) compared with a common variety (*Armadillidium vulgare*)

the wondrous strong and wickedly sharp, sickle-shaped dactyls of their many legs into the unsuspecting palm or finger of the would-be collector.

The young of these isopods just after hatching are worse than a pack of ravenous wolves in the way they assail the nearest fish in their search of a host on which to dwell and feed. Such lilliputian marine battles have, under favorable circumstances, been observed in tide pools, where the fish always seems to get the worst of it.

In speaking of wolfish isopods, Doctor Stebbing says that "if one were a literary fish, one would write with a kind of horror, on account of the appalling diligence which these so-called fish-bears devote to ichthyology. Not contented with persecuting ling and haddock, cod and halibut, they assail with equal fearlessness dog-fish and shark and tunny. An extraordinary feature in the life of some of the cymothoids is the virtual change of sex which is said to occur, enabling the father of one family to become in turn the mother of another, as though the ordinary marital arrangements were not sufficient to perpetuate their malicious brood."

In certain of the astacillid isopods the long antennae of the mother form "a sort of perch to which rows of young ones have repeatedly been found clinging, like wind-waving articles on a laundress's clothesline (Plate 44). One observer has recorded that 'the parent neither testified impatience of their presence nor seemed to suffer any inconvenience under the burden'," but nevertheless as they grew up they did seem ultimately to prove an annoyance, capable even of a fatal termination to the mother if they did not in time go to seek their fortunes in the world.

A striking form among the isopods is *Bathynomus giganteus* (Plate 45), one of the giants among crustaceans, growing to a little over a foot in length. The largest amphipod, *Alicella gigantea* (Fig. 33), is less than half the length of the largest known isopod, but in tenuity of body some amphipods take first place. Many visitors to the

Museum ask to see the skeleton shrimp. They refer to the amphipod *Caprella* (Fig. 34), which for all its slender build and lack of edible meat is one of the best known of crustaceans. *Caprella* turns a ghostly white after being

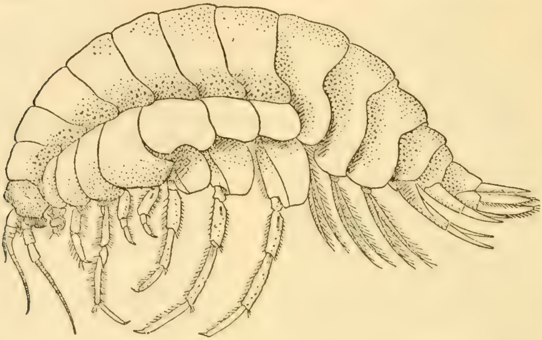


FIG. 33. The largest known amphipod, *Alicella gigantea*. A female five and a half inches long (reduced). After Chevreux

pickled for any length of time, but in life it is among the most adaptable of animals in reproducing the color of its surroundings. Its bodily form is equally imitative of its usual habitat, and as a result of this capacity for mimicry *Caprella* is hard to find, even though it occurs in great numbers. Not without reason is it called "skeleton shrimp": dwelling among the finely branched seaweeds, bryozoa, and hydroids, in shape and posture and color it is for all the world like a short branch of any of these marine growths.

Do not think that the skeleton shrimps are the only mimics among the amphipods. Some of the plumper fellows, too, like the pelagic genus, *Mimonectes*, are no mean imitators. Except for an odd little tail, without which *Mimonectes* wouldn't be an amphipod, the resem-

blance of the large transparent body of one of these to a floating jellyfish is well-nigh perfect.

When one beholds the hordes of fish that subsist on amphipods alone, the mere number of these crustaceans

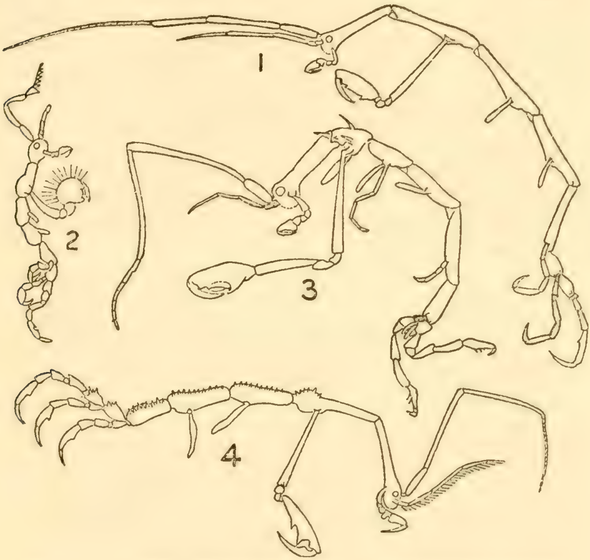


FIG. 34. Caprellid amphipods, aptly called skeleton shrimps, which in color, shape, and posture mimic marine growths. 1, 2, and 4, *Caprella;* 3, *Dodecas*. After Mayer

in the world makes one marvel. Several pelagic amphipods form at times a very considerable part of the diet of the herring and the mackerel. And when the pelagic amphipods are plentiful, then does the Biscayan tunny fishery flourish; when the amphipod food supply falls off, just so surely does the fishery languish. Amphipods that

frequent the sea bottom likewise supply much of the food of bottom-feeding fishes of the flounder tribe.

Certain birds also profit largely from the teeming numbers of amphipods. Mr. F. J. Stubbs calculated that in a square mile of sand on the Westmoreland coast of England there were, on an average, twenty amphipods inhabiting each square inch, and that the total weight of crustaceans for the area was seven hundred tons. He was surprised to observe that the only species of bird which seemed to feed on this particularly rich food supply was the black-headed gull.

The amphipods burrow in the sandy mud, making U-shaped passages about two inches in depth. Mr. Stubbs gives a graphic description of how the black-headed gull procures this crustacean food.

> The Gull stands in the water, and, holding its body horizontally, *dances* vigorously with alternate steps for a minute or more, but with no change of position. This action on the sand, possibly by filling up the burrows, alarms the crustaceans, which rise to the water and scatter in flight. As soon as they appear the bird stops its dance for a second or so, and, still remaining precisely in the same spot, snaps in the water at the swimming animals. On imitating the action with the tips of my fingers, and, of course, with the same result, I found that the crustaceans were readily detected by the sense of touch as they struggled to the water; and this suggested the possibility of the webs of the Gull's toes being used as tactile organs. The point is well worth consideration, for if established it would explain the presence of highly developed webs in birds which are addicted to wading but rarely use their feet in swimming.
>
> Sometimes a Gull would remain in one spot for so long a period as half an hour, gravely and patiently dancing the whole of the time. The result would be a craterlike depression six inches in diameter and an inch deep; but, if the birds were not disturbed, they would move gradually *backwards*, and in the course of a few hours make shallow furrows varying in length from a foot to twelve yards. One furrow that I measured was exactly twelve yards long, and had occupied its maker for at least three hours, and possibly twice this time. Now, allowing the width of the disturbed sand to be six inches (really this is the distance between the summits of the ridges thrown up on each side of the furrow), and the number of crustaceans twenty to the square inch, we find the total weight to be about a pound and a half. The

greater part of this would go down the throat of the bird, for I do not think that many of the crustaceans are allowed to escape once they are driven from their burrows.

Division Eucarida

Order Euphausiacea

Men and whales alike, on purely selfish grounds, would put the two orders contained in the division Eucarida first in importance among Crustacea; for these two orders are our old friends the Decapoda, preferred of men, and the Euphausiacea, preferred of whales. But however much they may be strangers to his palate, the euphausids are not unknown to man. No traveler on the Atlantic or Pacific Ocean, especially in the colder reaches, who has leaned over the rail of his ship at night can have missed the sparkles of light in the waves turned back from the vessel's sides and in its wake. These are the flashings of the tiny "lamps" ornamenting the bodies and appendages of euphausids. For all of them except a single genus have organs capable of emitting light. (See Plate 32.)

A euphausid is, perhaps, in an evolutionary sense, a grown-up mysid. It has a carapace which is fused dorsally with all the thoracic somites, and beneath which feather-like gills show plainly. As in the mysid, all of the thoracic appendages carry swimming exopodites, giving the legs the characteristic split-foot appearance. Euphausids are distributed the world over, but only in salt and brackish waters; unlike the mysids, they seem to have no fresh-water representatives. Most species of them range from half an inch to an inch and a quarter in length. The largest known euphausid is *Euphausia superba*, a handsome, brilliant-red fellow exceeding two inches in length. All expeditions to the Antarctic encounter them.

This giant and at least one other species of euphausid constitute the major part of the diet of the Antarctic whales. Sixty-two per cent of the world's whale oil,

taken from some thirty thousand whales each year, originates in the Antarctic region and depends wholly on the euphausids the whales get to eat. A moderate-sized blue whale tucks a mere two or three tons of them under his waistline at a meal! And whales are only one of the many kinds of animals that feast on this rich and plentiful food; for the seals and the penguins and petrels of these southern seas are almost, if not wholly, dependent on the euphausids. The North Atlantic *Meganyctiphanes* is a prime whale food, and the finback is at times literally packed with them. The finback is but one kind among a number of the whales that eat euphausids, and *Meganyctiphanes* is but one kind among a number of the euphausids eaten by whales.

Order Decapoda

Second of tne eucarid crustaceans and topping the crustacean scheme of things is the order Decapoda. Systematically it is subdivided into two major groups—the Natantia, or swimmers (best described as the true shrimps or prawns), and the Reptantia, or crawlers (crawfishes, lobsters, crabs, and their allies). As the name Decapoda implies, the members of this order are ten-footed. Quite readily may they be distinguished by this character and by the well-developed carapace which covers the united head and thorax. It is true that in some crablike forms—the lithodid and the porcellanid crabs—the hind legs are small and sometimes tucked in under the edges of the carapace so that their possessors appear to be eight-legged rather than ten-legged; also that in some of the lesser known shrimps one of the five pairs of thoracic legs may be suppressed; but all in all the build of a decapod is so unmistakably shrimplike or crablike that we have no hesitation about its proper classification.

In only one group of decapods do the young hatch out in a nauplius stage, for all the world like a barnacle or copepod nauplius; and only in this same group, also, do the

females deposit their eggs instead of carrying them until they hatch. The members of this group are called peneids. As yet the life history of these valuable food shrimps is rather imperfectly known. We do know the nauplius and

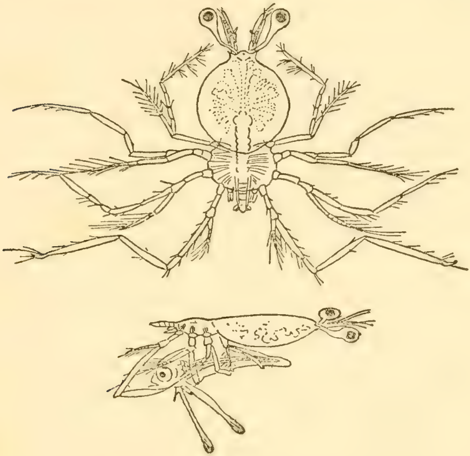


FIG. 35. Upper, dorsal view of phyllosome larva of the English rock or spiny lobster (*Palinurus vulgaris*) (x 7). Lower, a larva capturing a baby angler fish. After Lebour

several protozoeal stages, a zoea, and schizopod or Mysis stage; but beyond and between, nothing. And the reason we know nothing of the other stages is because, as mentioned above, the peneids do not carry their eggs until they hatch.

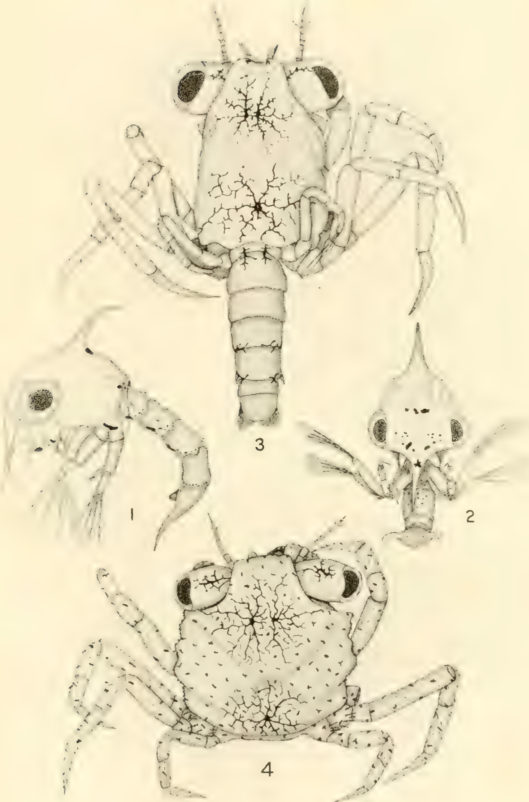
No decapod except the peneids hatches out of the egg at a stage earlier than a zoea, and a few species leave the egg not so very unlike their adult forms. The spiny lobsters and the shovel-nosed shrimps are unique in hatch-

ing out in a form quite unknown in other Crustacea. This form is called the phyllosoma-larva or "glass" shrimp, so thin, flat, and transparent is it (Fig. 35). Swimming in its native element it just can not be seen by human eyes. Only in a bucket of water in which the sun is shining can one detect its presence by virtue of the shadow it casts, which is due to the difference of the refractive index of the phyllosome from that of the surrounding water. Out of water, at the bottom of one's net, it appears as a bit of crumpled gelatine, so easily does it "kink" when removed from its supporting medium. The little phyllosome passes through a dozen or two larval stages which give no hint at all of its adult form. Suddenly it transforms into a tiny, smooth, nonspiny lobsterlike being, itself so unlike the adult that it remained for a long time unassociated in the scientist's mind with the spiny lobster. Finally it acquires its familiar adult form.

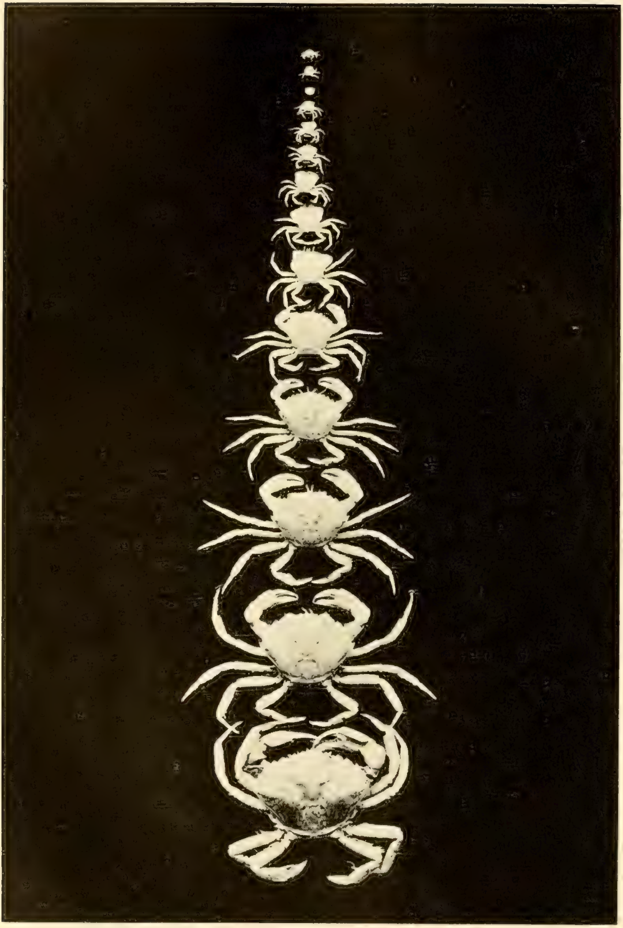
To illustrate the life history of a typical reptant decapod, we can do no better than make use of portions of Dr. O. W. Hyman's vivid account of the fiddler crab.

> Hatching always occurs just at dusk—that is, between 7 and 8 o'clock. The mother crab comes down to the water's edge and fans her abdomen back and forth to aerate the eggs as usual. If the embryos are ready to hatch, however, the little larvae burst out of the egg shells and at each forward flirt of the abdomen a small spray of young larvae is shot forward into the water.

The young crab, or zoea, thus catapulted from the shelter of its mother's abdomen, measures only a millimeter in length when fully extended; and as in swimming the body is bent double, the swiftly moving larva is only about half a millimeter in length and the same in width (Plate 46). When the zoea bursts from its eggshell it at once swims to the surface of the water, where it finds conditions that give it a chance to survive. But it is well that the brood is hatched at dusk and has all night to be scattered by the tide before the young members enter upon the adventures of their first day.



Stages in the development of the fiddler crab (*Uca pugilator*). 1, side view of the first zoea. 2, front view of same. 3, megalops. 4, first crab stage (some legs lost). After Hyman



The finest series of cast crab shells known. Collected from one individual of the English shore crab (*Carcinides maenas*), by Mr. and Mrs. H. J. Waddington (x 1/3). Courtesy of the British Museum

The zoea begins to feed upon the smaller of its countless companions at once and for the next four or five days the mouth parts are catching, crushing, and swallowing tiny animals and plants. As a result of this feeding the zoea begins to grow. Its inelastic chitin coat soon becomes too small. A new covering of larger size is formed beneath the old. For a short time now the zoea becomes motionless and sinks toward the bottom. The old coat then splits along the back at the place where the abdomen joins the cephalothorax. The zoea first pushes its body through the slit, and then draws its abdomen and appendages from their old sheaths. This is the first molt. The zoea which emerges is somewhat different from the first hatched zoea and is called the second zoea. The molting period is a perilous time in the life of the zoea. The larva is quite helpless, but fortunately it is almost invisible against the sandy or shelly bottom on which the molt generally occurs.

In the "sand fiddler" studied by Hyman there are zoeal molts at about weekly intervals—four in all, and marked increase in size is noted after each molt. The fourth zoea is just twice as long as the first. The fifth "is no longer the graceful, restless, palpitating form of larva that suggested the name Zoea, 'Life,' to describe it. The body is so heavy that the maxillipeds can only keep it at the surface for short periods. Most of its life is spent drifting along near the bottom."

The last zoeal molt takes place when the animal has been living at sea a little over a month. Of the hundreds of young hatched by one female only a score or so will have survived through this molt, which marks the transition to a new larval stage.

The larva that stretches itself after jerking loose its last attachments to the zoeal skin could hardly be recognized as derived from a zoea—even the changed zoea of the fifth stage. As a matter of fact, it was described by earlier naturalists as an entirely separate genus and called *Megalops*, from its large and prominent eyes. This name has been retained to describe this stage in the larval history, just as pupa describes the second stage in the larval history of the butterflies. The megalops is a larva far different from a pupa, however. Instead of being a motionless, sluggish creature it is a powerfully swimming corsair of the ocean's surface.

. . . It is easily seen as it darts about the surface. The sensory organs are now well developed. The eyes are large and well formed.

In the base of the antennule there is a statolith, and the animal swims about in any direction and can change direction quickly and accurately. It is no longer guided in its movement solely by its reaction to light, but is independent of this tropism and seeks its prey at all depths. It remains at the surface most of the time, however, as food is most abundant there. . . . The animal can hear, in the sense that its delicate hairs perceive the vibrations in the water just as the ears of higher animals record the sound waves of the air. These "hearing" hairs are especially located on the antennae and antennules. . . .

The shape of the body is now more that of a crab than that of a zoea, but in some respects it is intermediate between the two. The spines of the zoeal carapace are lost and the body is somewhat flattened from above and below. However, it is still considerably longer than broad and in this respect resembles somewhat the body of a shrimp. In fact the megalops may be said in general to have the body of a shrimp or crayfish with the legs of a crab. The abdomen is like that of the crayfish and in swimming is carried extended straight out behind. When the animal comes to rest, however, it is folded under the body and the megalops then looks very much like a tiny crab. . . .

The megalops swims about for nearly a month. Unlike the zoea it does not go through a series of molts during this time, although it undergoes considerable internal development. After some three or four weeks of its roving existence these internal changes begin to affect its swimming powers. The swimmerets or pleopods begin to shrivel up slightly. After this begins the megalops is glad to find some convenient place to cling and hide. . . . This loss of the power of the pleopods for swimming marks the end of the sea life and adventures of the larva. When these organs lose their function it will never again be able to swim.

After perhaps a week in its shelter the megalops molts, and out of the megalops shell crawls what is unquestionably a crab, though hardly recognizable yet as a fiddler. After four or more molts in the crab stage the young crab begins to develop secondary sex characters distinguishing the male from the female.

The young crab after this lives just like the adult. It gets its food from the sand on the beach, digs its burrow between the tide lines, comes out and feeds when the tide is falling, and hides in its burrow when the tide is coming in. It continues to grow, and as it grows continues to molt time after time. Of course, as the crab grows larger it digs a deeper and larger burrow. . . .

. . . .

When the weather begins to get cold in the late autumn all the crabs on the beach crawl into their burrows for the winter hibernation. The unlucky larvae and little crabs that are not yet strong enough to dig their burrows perish of exposure during the first cold weather. All during the winter the crabs remain buried. . . .

As soon as the first warm weather comes in spring all the little fiddlers become lively again and dig themselves out. Some of the young crabs of the preceding summer may have become sexually mature by this time and by early April they lay their eggs, and soon the sounds and adjacent sea are receiving new swarms of delicate, active zoeas, setting out upon the great adventures through which every fiddler crab must pass in its youth.

But after all, what are youthful adventures compared to those of a more mature age? The sand fiddlers are agile runners, but a man can easily overtake them. As a protection from their enemies they rely in the main upon their burrows. These are dug along the beach just below the high-tide line and extend downward a foot or more at a very steep angle. When the tide comes in the crabs crawl into their burrows, and the beating of the wavelets soon stops their doors with sand. When the tide begins to ebb and leaves the beach, now all wet, the fiddlers dig themselves out again. The excavated sand is gathered in wet balls and distributed along the beach at a distance of about six or eight inches from the openings of the burrows. It is to be expected that the next time the fiddler enters his burrow he will be in a hurry and want a clear road. After he has made sure of his means of retreat, he joins his companions at the water's edge.

Each wavelet of the receding tide casts up on the beach a tiny "windrow" of sand. There is much more than sand in this "windrow," however. Among the sand grains are caught and left countless numbers of microscopic plants and animals that dwell at the surface of the sea. The fiddlers walk along the "windrows" as they are formed and with the spoon-shaped tips of their smaller claws or hands scoop up the food-laden sand and stuff it into their mouths as fast as their hands will work. At meal times the females have an advantage. Both of their hands have spoon fingers and both are kept busy. The crabs seldom enter the water, although their station so close to the water's edge exposes them to many a ducking in the wavelets. At times, too,

when an enemy approaches from the land side the fiddler may elect to hide in the water, partially burying himself in the loose sand, rather than run for the burrow. These short intervals in the water are the most hazardous periods in the lives of adult fiddlers. Blue crabs like to lie in the shallow water and wait for little fish that get stranded, and they have learned that they can also pick up a considerable number of fiddlers. When the tide begins to rise and no new "windrows" are left on the beach the fiddlers will wander elsewhere in search of food. They will climb about over stones or piling at the water's edge and always there are a few that lose their footing in spite of their eight legs and fall overboard. A fiddler overboard is a fiddler lost. They can not swim, and hungry fishes, like the black sea bass and the sheepshead, quickly gobble them down.

As with the fiddler, so with other crabs and decapods with variations to best meet the exigencies of their existence. Concerning the length of time it takes for a typical decapod to reach maturity we cite the opinion of Churchill, who gathered data on the blue crab. This, he says, showed that growth from a megalops larva to the usual adult size required 208 days. During this time fifteen molts took place and the crab grew from a width of a twenty-fifth of an inch to seven inches. The usual term of life for the blue crab, male and female, seems to be about three years. Pearson deduces that the English crab, *Cancer pagurus*, keeps on growing for some twelve years. After the fifth year there is reason to believe that the male molts only once in two years and the female once in three. Judging from the growths of shell and barnacles on old specimens, molting may cease completely as age advances. Incidentally, the finest series of cast shells known is one made up of fifteen shells cast by an English shore crab, *Carcinus maenas*, over a period of three years. The crab molted seventeen times, and all its cast shells are shown in the accompanying photograph (Plate 47) except two which were accidentally destroyed.

We do not know which of the crustaceans is the longest-lived, but it may well be that the full-grown lobster deserves this title of distinction. Lobsters have been known to attain a weight of thirty-five pounds and an age which

Herrick estimates to be about fifty years. A specimen of this weight and age will measure two feet in length of body alone. His large crushing claw may well run to a length of twenty inches and an equal girth; that is, it is as big around as a man's head.

The giant among Crustacea is, of course, that rather fearsome-looking giant spider crab of Japan and the North Pacific, *Macrocheira kaempferi.* (See Plate 36.) It spans twelve feet from tip to tip of outstretched arms, and the body measures eighteen inches across. The spindly legs are almost as big around as an old-fashioned wooden curtain pole.

For the largest fresh-water crayfish we must go to Tasmania, where one species is all of two feet in length and weighs eight or nine pounds. It is excellent eating and much sought after, but the small streams which it frequents seem an incongruous habitat for so large a crustacean.

Within the borders of the United States we have a giant fresh-water shrimp, *Macrobrachium jamaicense.* The largest specimen I know of weighed three pounds; its body length was ten and a half inches; the feelers, which were missing, were said to have been twenty-six and a half inches long; the larger claw of its sturdy pair measured thirteen and a quarter inches. It hailed from the Devil's River, Texas.

Among many fresh-water decapods the young hatch out substantially in the form of the adult. One can readily see the advantage of this to species that may live in steep mountain torrents debouching into the sea, where it is but a hop-skip-and-jump from fresh to salt water; for if the young hatched out in a helpless larval stage they could not escape being washed into the sea, in which they would perish from the salinity, just as we would be overcome by drinking highly concentrated salt solutions.

But among marine species such a suppression of the usually numerous larval transformations is of great rarity.

Of the thousands of species of marine crabs, in but three is there definite evidence of a complete suppression of the larval stages such as we know in fresh-water forms.

The first case of direct development in marine crabs was discovered by Dr. Mary J. Rathbun, Associate in Zoology of the Smithsonian Institution. She found in the brood pouch of a small spider crab—*Naxioides serpulifera*, from the Monte Bello Islands (off the northwest coast of Australia)—young crabs in adult form; and not only in one stage, but in two, showing that at least one molt was undergone while the offspring were still under maternal care. It is of more than passing interest that the other two known instances of direct development in marine crabs should likewise have been found in Australian waters; both were dromid sponge-carrying crabs—*Petalomera lateralis* and *Cryptodromia octodentata*.

The philosopher might find food for reflection in the fact that the most famous of all crustaceans is a thief—the robber crab of the South Seas, *Birgus latro* (Plate 49). He climbs the coconut palm to cut down the meaty nut. Many people have observed the creature at close range and even had him in captivity for considerable periods of time, but never have his habits or his whole life history been investigated with any degree of completeness.

But this much we know. The robber crab is an agile and ready climber, be it on coral blocks, volcanic cliffs, trees, door jambs, posts, or almost anything else that has a perpendicular face. Two of my friends who have had these crabs as pets in their native islands have told me how their sharp-pointed feet would find a foothold in the crevice between the door jamb and the wall and so permit them to climb up with ease; and how on occasion they would travel like a sloth, though not so slowly, along a wire stretched across the room. Just how the crab was said to have descended, I do not at this moment recall. As he makes use of window frames as well as of door jambs, he may drop from the sill to the ground. Kopstein

claims that falling with folded legs is his usual mode of descent from palm trees, and says that under these circumstances the crab has to restrict his activities to low trees or else suffer the consequences of wrecking himself on the stones and coral blocks that are commonly found in the coconut groves. But if Kopstein is right in his claims we must admit that the robber is quite a crab to be able to single out the low palms from the high ones in order to make a safe descent.

The alleged native method of catching the crabs throws light on the mode of descent of the robber crab. The story is that when a native locates one of these big crabs up a palm tree, he climbs part way up himself and fastens a girdle of grass around the tree. Then he descends. The crab, in his turn, crawls backward down the tree trunk, feeling behind him as he goes. When he feels the girdle of grass he releases his hold on the tree, under the impression that he has reached the ground. As a result he tumbles heavily to the earth, either stunned or killed. At any rate, it is then an easy matter for the native to catch him and tie him up before he recovers from the shock of the fall. The habits of these high-climbing animals do differ in different localities, a fact which accounts for the wide divergence in the accounts about them published by various credible observers.

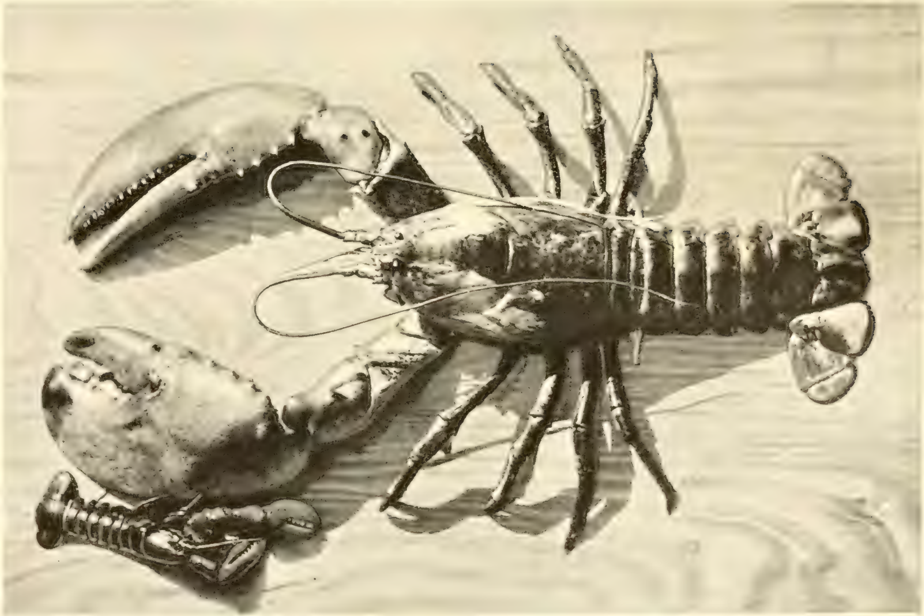
Professor Sluiter tells us that he has himself seen robber crabs "climbing even to the top of the coco palm and mangrove trees, of 20 m. [over 60 feet] height"; while one he had in his laboratory liked to climb to the tops of the iron pillars supporting the roof—pillars about sixteen feet high and three inches in diameter.

In some districts it would appear that the robber crab makes his home at some distance from the sea, on stony plateaus thirty or forty yards above the shore line; while in the Solomon Islands, Guppy has seen specimens at an elevation of 300 feet. It is here, too, that the robber crab ejects large burrowing land crabs from their homes and

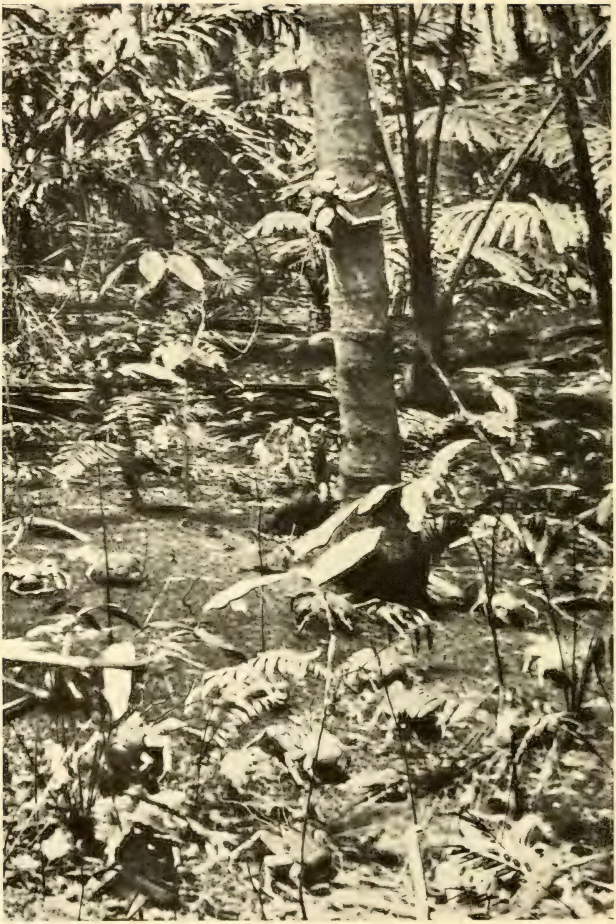
takes over their underground habitations. Generally in the South Seas the robber crab seems to stay very close to shore, where he hides among the coral blocks and crevices of the reef, and, more rarely, under the roots of mangroves.

Throughout its range this crab is a nocturnal animal; but Andrews says that on Christmas Island (in the Indian Ocean) it moves about the forest even in the brightest daylight, and he has photographs to prove his statement.

Baiting is an approved method of capturing the robber crab, but hunting him is more popular. On some of the South Pacific islands it is a sport attended with considerable excitement, because of the animal's wary habits, great strength, and bulldog tenacity. Except on Christmas Island the chase is conducted at night, when the robber crab ventures from his daytime hiding places to feed. Improvised torches and lamps furnish the necessary light. When hunting over the reefs in the dark, the well-shod foreigner is at a decided disadvantage compared to the barefooted native, who can stalk the wary game noiselessly. The crab usually scuttles off with awkward yet effective backward rushes, covering several yards with each rush. He never turns tail to the danger. His claws are held presented for instant action, pincers pointing downward, in a posture like that assumed for guarding the head and face in sword exercise, but with the added advantage that it serves to guard not only the crab's head and eyes but his "solar plexus" as well. Then, too, he holds one or both of his needle-sharp second legs poised for a dangerous downward thrust. His poorly armored abdomen is his most vulnerable point. Altogether he is a most doughty combatant when fully on guard, and one that seems to have no enemies to fear except man; although pigs which have run wild are said to attack and destroy the "robber". No doubt if just one pig, or even if just a few pigs, attacked one of these powerful crabs, the crab would be more than a match for his enemy. But wild pigs



A giant specimen of the American lobster (*Homarus americanus*) compared with an ordinary specimen. Length from tip of tail to rostrum, twenty-four inches. Crushing claw sixteen inches long, nine inches wide, and five inches thick. Weight, twenty-eight pounds. Courtesy of Whipple Brothers, Matunuc Beach, Rhode Island



Robber crab (*Birgus latro*) climbing a coconut tree on Christmas Island.
Photograph by Andrews. Courtesy of the British Museum

have a habit of running in droves, and in a combat with such a drove the odds would be heavily against the crab.

When surprised by torchlight the robber crab must be grasped with celerity by the carapace and held at arm's length until he can otherwise be secured. Woe betide the unskilled hunter who should get caught in his fearsome nippers; for the crab will amputate a finger quicker than it takes to tell about it. Fortunately, should he gain a hold with his claws, there is a little trick that results in instant release, and that is to give the tenacious fellow a rap on the abdomen. Otherwise, he seems able to retain his grip for hours at a time.

Professor Wolf once had occasion to test the endurance of one of these suspended coconut crabs, which had happened to seize the handle of his insect-collecting net. As he couldn't wrench the net out of the animal's grasp, he placed enough stones in it to weigh five and a half pounds. For one full hour the crab showed no sign of fatigue, and it was some hours later before he finally let go his hold. One of Kopstein's captives, a grown specimen about a foot in length, got out one night by cutting a hole through the inch-and-a-quarter wooden wall of his inclosure. This particular animal had pincers as big around as the fist of a ten-year-old child.

Some robber crabs grow to eighteen inches in length and no doubt have claws as large and strong in proportion. No other known animal has the strength and ability to open the tough-husked coconut unaided. The robber crab accomplishes this with neatness and dispatch, and gets out the inner nut as cleanly as any native. He will tackle a tough, ripe nut as readily as the tenderer young green ones, to which many authorities have assumed that he confined his efforts. That the animal can tear off the extremely smooth, coarse-fibered outer casing is less to be wondered at than the facility with which he breaks his way through the adamantine nut within. Commencing operations at the eyed end—structurally the

weakest part of the nut—he bites and grinds and nips and perhaps pounds his way through to the juicy pulp within. The entrance he makes need not be overly large, and no sooner is it effected than he holds the shell with his heavy claws and uses his smaller, hinder legs to reach in for the pulp.

Robber crabs from regions where coconuts are to be had will starve rather than take other food; though where coco palms are lacking, as on Christmas Island, they seem willing to eat the fruits of other plants, such as the sago palm and screw pines. A robber crab can readily stow away about two coconuts each three days. In the course of a year, at that rate, he would consume the annual production of two or three coco palms—some two hundred and fifty nuts. So it can readily be seen that he must be reckoned with where coconuts are grown for profit. But his rich diet has made him such a fat and juicy morsel himself that he is considered an epicurean treat by the non-Muhammadan natives, and thus a destructive pest becomes a marketable product. One crab's abdomen will yield as much as a quart of oil. The Chinese, especially, value this crab's flesh as a delicacy; and in regions where the robbers abound, these people frequently keep them tethered about their dwellings—after depriving them of their powerful claws—to fatten them for the table. The orthodox Muhammadans, on the other hand, it is said, are twice interdicted by their religion from partaking of this delectable dish: first, because the animal uses its hand to convey its food to its mouth; and second, because it leads a double life, being a marine animal that passes its life upon the land.

The robber crab does go down to the sea, however, when its eggs are about to hatch, so that its young may be rocked in the cradle of the deep, the ancestral home of all Crustacea. The first free larva is a very ordinary form, like the usual hermit-crab zoea. There is no earmark in the marine young of the robber crab to indicate any great

A scene in Tahiti: The robber crab (*Birgus latro*) eating a coconut, and fiddler crabs (*Uca tetragonon*) fighting and playing on the beach. By E. Cheverlange

difference between it and the young of the other hermit crabs, which spend their lives in deep water and never venture near the land.

As a result of being so assiduously hunted on economic as well as gastronomic grounds, the robber crab seems to be rapidly disappearing, and in fact has been exterminated on many islands where it formerly abounded.

Division Hoplocarida

Order Stomatopoda

In the stomatopods, or squillas, we have, as it were, an afterthought to the Crustacea. A small and homogeneous group, rather closely adhering to type, they form the single order constituting the fourth and last division of the eumalacostracan Crustacea—the Hoplocarida. Perhaps their most characteristic features are their "jackknife" claws, so like those of our common garden mantis that they are known as mantis shrimps wherever English is spoken. The relatively large and much flattened abdomen is also a very characteristic feature, as is the small, flattened, hinged rostrum, the like of which we have not seen since we left the Leptostraca, the lowest of the malacostracan crustaceans. The eyes, as well as the antennules, are borne on movable "rings" or segments, a character so unusual among the Crustacea that it distinguishes the stomatopods from all other members of the class. Also, the stomatopods are foot breathers in a more specific sense than are other crustaceans, for each of the pleopods or abdominal feet is largely a plumose respiratory organ, and not an accessory to egg-carrying.

The stomatopod young are queer little creatures, as odd in their way as are the phyllosome larvae of the spiny lobster. As glassy as any phyllosome and as long-spined of carapace as anything afloat, these larvae are all planktonic, though the eggs are hatched in the shelter of some recess or hiding place.

Stomatopods are burrowers in mud or sand bottoms, or

else they preempt the burrow of some other marine excavator; some live in the interstices of coral reefs. All seem to be most suitably adapted in form and color to the mode of life they lead. In the spinous armature and color of its telson (Fig. 36) one species mimics the tiny sea-

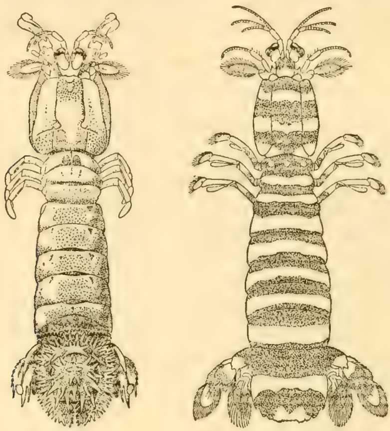


Fig. 36. Stomatopods, or mantis shrimps. Left, *Gonodactylus guerinii* (after Brooks). Right, *Lysiosquilla maculata* (after Kemp), showing extremes in ornamentation of the telson

urchin so closely that when it is hidden in its coral burrow it has fooled even observant naturalists. At such times the spinous, urchin-resembling telson acts as a plug to the entrance of the burrow, effectively concealing the rest of the stomatopod within. The telsons of nearly all, if not all, stomatopods are very characteristically sculptured. Some indeed are unbelievably bizarre in appearance.

A stomatopod larva in season must be the ogre of all the other planktonic crustacean young, for its formidable

Care of eggs by stomatopods. A composite picture showing *Squilla mantis* carrying eggs, and *Gonodactylus oerstedii* tending eggs in coral rock burrow. After Giesbrecht and Brooks

claws do not hesitate to seize anything, even creatures as large as itself. Such was the observation made by Dr. Marie V. Lebour in an aquarium of the Plymouth Marine Biological Laboratory in England.

Once one of 5 mm. was seen to catch a Upogebia larva nearly as long as itself (Fig. 37). For catching such a large animal the chelae come into play and hold the prey tightly between the two terminal joints.

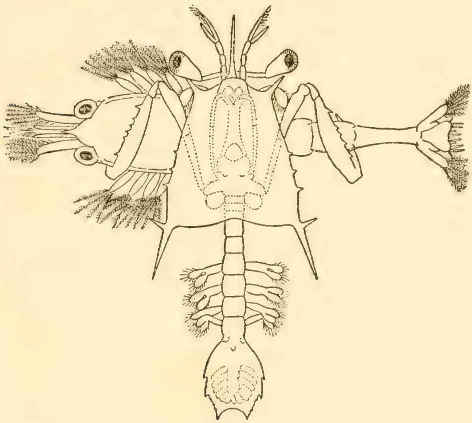


FIG. 37. A larval stomatopod capturing the larva of a burrowing shrimp (*Upogebia*) (x 12). After Lebour

For some time it swam about holding its burden like a baby and beautifully balanced. When first captured the Upogebia was very lively, but soon subsided and died, apparently from intense pressure, but after about half an hour it was dropped and not eaten. Possibly it was too big and had exhausted the Squilla too much. It is certain, however, that the purpose of the chelae is for catching and holding the prey. The Squilla larva always goes towards the light and dances happily up and down with an eager alertness which suggests the constant excitement of capturing live food.

"Like father, like son," certainly applies to the stomatopods, for the adults are unquestionably despoilers of all

other kinds of crustaceans. It is not without reason that the wicked and powerful claws of the larva, when fully grown, have earned their possessors the name of "split thumb" in Bermuda and in the West Indies. They are the thugs of crustaceandom, hiding in their runs and warrens by day and consummating their murderous deeds under cover of darkness. Only exceptionally do we find them feeding by day. They can be caught on the coral reef by forcing a sea-cucumber to part with its viscera, a tidbit which seems to have the greatest attraction for all stomatopods. Carnivorous in a high degree, they will eat meat of all descriptions—portions of large crustaceans, crabs, fish, mollusks, worms. They prey upon all available species of shrimp and upon other stomatopods, for cannibalism is not beneath these "racketeers" of the seas and littoral zone. Especially fond of their relatives are they when these are soft and toothsome, in the molting stage. The stomatopods like their soft-shelled crabs as well as you or I. Live fish they catch whenever they get the chance. Sea-anemones are good to eat and are much eaten by the peoples of the Mediterranean region, and some of the stomatopods of these same shores feast eagerly upon them too.

The sharp claws of stomatopods are quite obviously as serviceable for defense as for offense; and to these weapons can be added, if need be, the strong telson spines and the sharp armature of the uropods of all species, which can be lashed out on occasion in all directions by the especially flexible and loose-jointed body. But, as Wilhelm von Giesbrecht quite naturally inquired twenty years ago, against what enemies do these active marauders find it necessary to defend themselves? His inquiry revealed that though some observers had seen various sea-urchins in the act of devouring squillas, it would appear that the victims were either moribund or otherwise incapacitated specimens; for such as were in full possession of their faculties seemed to have little or no difficulty in tearing

loose from any of the urchins' tube feet that may have become fastened to them. Octopuses are notorious enemies of crustaceans, particularly crabs, and in aquariums are nothing loath to tackle so porcupinelike a fellow as the stomatopod and to put him away, spines and all, in spite of the repeated blows they suffer in arms and body from the vicious claws and sharp tail spines of the struggling victim. Still, Professor Giesbrecht thought they were not to be reckoned as especial enemies of the active stomatopods.

The late William Keith Brooks wrote of stomatopods;

They are solitary in their habits, and I have never found two in the same burrow. They are pugnacious to an astonishing degree, and their fighting habits, as I have observed them in aquaria, are so fixed and constant that they must be constantly exercised by the animals when at home. When two specimens are placed together in an aquarium they at first appear to be unconscious of each other, but more careful examination will show that their eye stalks are in constant motion following each movement of the enemy. They soon assume a position in which they are face to face, although they may be on opposite sides of the aquarium, and the constant motion of their eye stalks shows how intently each movement is watched. Soon one attempts to get behind the other, but each such attempt is frustrated, until finally they are brought close together, face to face, and soon one springs suddenly upon the other and attempts to pinch some unprotected part. They then spring apart and eye each other again to repeat the attack at short intervals until one is disabled; the other then springs upon him and soon tears him limb from limb, disjointing all the free somites of the body and tearing out and devouring the flesh.

Concerning the care of the eggs by one species of stomatopod, *Gonodactylus oerstedii*, of the Bahamas, he said:

The animal molds or shapes the mass of eggs into a hemispherical cap, which fits over the convexity of the hind body and lies between it and the stone wall of the burrow (Plate 51). The parent reaches out to snatch at passing prey, but so long as she is undisturbed she remains in the burrow. When the burrow is broken open she quickly rolls the eggs into a ball, folds them under her body in a big armful, between the large joints of her raptorial claws, and endeavors to escape with them to a place of safety. The promptness with which this

action is performed would seem to indicate that it is an instinct which has been acquired to meet some danger which frequently presents itself. It would seem as if a cave in a solid rock were a pretty safe refuge from all enemies except a naturalist with a geological hammer, and it is difficult to say what the accident is which has thus been provided against. The larger heads of growing coral are often broken off by the waves, and loose fragments of rock are overturned by severe storms, and it is possible that, when alarmed by a violent shock, it flees from its cave to escape the danger of being crushed when the rock is torn from its place and turned over. At any rate its habit is the reverse of that of most burrowing animals, for they usually retreat to the depths of the burrow when alarmed. This is true of all the Stomatopods which I have had an opportunity to observe except this species, and the chief use of the burrow of *Squilla* [*Chloridella*] *empusa* is for refuge in danger, while *Lysiosquilla excavatrix* darts down its burrow at the least alarm and can not be driven out even when the sand has been dug up on all sides of it.

With this we conclude our sketchy survey of the orders of Crustacea. To compress so vast an assemblage into so small a space would be beyond the skill of man, but at least we have, metaphorically speaking, shaken hands with representative citizens of the five subclasses. Further acquaintance with some of their idiosyncrasies may make it easier for us to recognize them again.

CHAPTER IV

WHERE CRUSTACEANS ARE FOUND

WHERE we least expect them is often where we should look for Crustacea. The extremes of temperature under which they may carry on the business of life are little short of astounding. Our common fresh-water amphipod, *Gammarus limnaeus*, which is active under six to seven feet of ice on the Arctic coast of North America, occurs also in the water flowing from boiling springs in the Yellowstone National Park. The temperature in which it thrives here is nearly 100° Fahrenheit. The unicellular Protozoa, most resistant of animals to heat, live in Italian hot springs where the temperature reaches 130° Fahrenheit; the nearest approach to this achievement by another animal is made by an ostracod that is abundant in certain Algerian thermal waters, where the temperature ranges from 113° to 123° Fahrenheit. The recently discovered peracaridan *Thermosbaena* carries on the business of life at 112°.

The water a mile or more below the surface of any sea is exceedingly cold and, barring local differences, uniformly so. The calculated mean temperature below two thousand fathoms—more than two miles—is something like 35° Fahrenheit, and bottom ooze brought from that depth, even at the equator, feels as cold to the touch as melting ice. The fact that all the ocean abysses are chilled explains why the same species of animal may be found at opposite ends of the earth, and may pass quite comfortably beneath tropic seas, where surface temperatures are over 80° Fahrenheit. One of the largest of the amphipods, *Eury-*

thenes gryllus, is found from Cape Horn to Greenland; and so far as I am aware it comes from the greatest depths at which any crustacean has ever been taken—three and three-quarters miles down.

A specimen of the shrimp *Benthesicymus moratus* taken by the Prince of Monaco from a depth of three and a half miles, was "soft and lacking the carapace and most of its thoracic appendages." It is a well-known fact that animals brought up from great depths often reach the surface in a most wretched condition—soft and flabby, and, if they are fishes, turned inside out. This is to be expected considering the pressure to which they are subjected in their normal environment—something like four tons to the square inch.

Going toward the other extreme of the vertical scale, we find that amphipods and isopods have been collected in the Ecuadorean Andes at an elevation of 13,300 feet. At an elevation just 800 feet lower than this, in the Peruvian Andes, lies Lake Titicaca, that mighty sea of fresh water 138 miles long and nearly 70 miles wide at the widest point. In this famous body of water Alexander Agassiz dredged nine species of Crustacea, of which seven were then new to science.

Many groups of Crustacea are represented in the underground faunas of the world. Blind crayfishes have long been known from our more famous caves, and amphipods, isopods, copepods, and shrimps are to be numbered among the residents of such places.

Even the trees have their crustaceans. In the pockets of water formed at the bases of the leaves of the tropical bromelias we find a species of ostracod never found anywhere else. Copepods are known from the reservoirs of pitcher plants. Crustacea are as ubiquitous as mosquitoes, breeding in the merest bit of water that may persist long enough for the performance of a hasty life cycle.

Since Fritz Müller first discovered the ostracod *Metacypris bromeliarum* in the auxiliary catch basins of the

Brazilian bromelias, the search for crustaceans in queer places has produced remarkable results. Tropical epiphytes, palms, and similar plants affording more or less permanent reservoirs of water, however tiny, pitcher plants of all kinds, damp and sodden moss hollows, and knot holes in trees have been examined. None of these unusual types of habitat has failed sooner or later to yield some form of crustacean life.

If we may believe Dean Worcester's account, Crustacea are even to be met with flying through the air. We have long known that several pelagic copepods are energetic jumpers. In proportion to their size, their leap into the air is literally a modest flight, and has been described as such for *Pontellina mediterranea*. Ostroumoff has observed individuals of this species launch themselves into the air by a powerful jump and then describe a long curve before falling back into the water. He insists that its flight is not to be compared to the hops of wingless crickets, but to that of the flying squirrel and flying fish; for it is well furnished with "feathered" appendages which, airplanewise, lengthen out the curve of its fall.

But Dean Worcester's flying Crustacea are something else. He reports seeing on three occasions in 1912 and 1913, in Philippine waters, animals that looked like crayfishes or shrimps and that appeared to measure from six to ten inches in length rise out of the water and fly, for several rods, after the manner of flying fishes.

Of the remarkable travels of crustaceans, none perhaps surpasses that of the mountain crab of the Orient, *Eriocheir sinensis* (Plate 53). *Eriocheir* means "woolly handed" and refers to the furry cuff of long hair enveloping each claw of this crab. In China the superstitious hold it to be the evil cause of the intermittent rat-and-mouse plagues that overrun the ripening fields of rice; they believe the rodents to be but four-legged transformations of the mountain crab. Even as early as the fourth century Yu Pau wrote: "In the year 283 A.D., all crabs in the District of Hwui-Ki

were turned into rats, whose kind covered the rice-farms and caused widespread destruction and devastation. When yet immature, these rats had hair and flesh but no bones, and were unable to pass over the dykes on the farms, but became vigorous after a few days." Though found at all times in the brackish water of estuaries, the mountain crab is first and foremost a fresh-water species, ranging up the Yangtse-kiang more than 800 miles from the sea. But in 1915 it was noticed by fishermen in the lower reaches of the river Elbe, in Germany! The most direct route between China and Hamburg is roughly 8,000 miles long, but this fellow most likely came by tramp freighter and spent months on the way. I can well imagine that some sailor dumped the first immigrants of this species to Germany overboard, perhaps to get rid of his live pets on signing off the muster roll. And now, under date of April 24, 1931, we read that these crab immigrants from the Orient are thriving so in German waters that they are seen by the hundreds clinging to the underpinning of wharves, that they interfere with bathers at the beach resorts, and that they greatly trouble fishermen by cutting their lines.

Journeys made by Crustacea on transported plants may be as great as the foregoing in distance traveled; but they must be far less hazardous for the animals concerned, which are traveling on a specially cared-for bit of their native environment. Vessel transport, too, brought the amphipod *Amphithoe penicillata* from Pondichéry, India, to the harbor of Marseilles; and at another time it brought a large west African swimming crab to the same harbor. The bottoms of ships have long been known as prime movers in the dispersal of certain forms of marine life through the oceans. The old days of wooden ships account for the universal distribution of that noted destroyer of wood, the isopod *Limnoria lignorum*, and his boon companion, the amphipod *Chelura terebrans*.

Any South Atlantic hydrographic chart contains repre-

Deep-sea peneid (*Plesiopenaeus edwardsianus*) taken from a depth of nearly three-quarters of a mile.
After Bouvier

PLATE 53

Woolly-handed Chinese crabs (*Eriocheir sinensis*) nipping off the young shoots in a rice field

sentations of "islands" of kelp which drift from the southern part of South America eastward past the Falkland Islands. These are natural rafts, some of which, I should judge, would carry anything short of an elephant. Certainly they carry many crustaceans, and we find the Falklands peopled with species common to South America.

The natural distribution of Crustacea holds the clue to a number of problems of zoogeography. I once picked up from the beach on the island of Juan Fernandez (off the coast of Chile) a grapsoid crab hitherto only recorded from New Zealand; and some time previously Professor Chilton had reported, also from South America, the occurrence of a New Zealand amphipod. Such natural-history linkages are significant indexes of what may have been the distribution of the land masses of the earth in past geological ages. The truly wonderful flora of Juan Fernandez goes back to Tertiary times, geologically speaking—twenty-five million years ago or thereabouts. It would seem that the genealogy of the New Zealand shore crab, found on the same island, must perhaps be traced back to as remote a past to account for its presence on the island that was once the home of the prototype of Robinson Crusoe—Alexander Selkirk.

Cabo dos Camaraõs and Rio dos Camaraõs were the names given by the venturesome Portuguese navigators of the fourteenth century to the well-known west African promontory and bay that bear these names today. The "Cape of Shrimps" and "River of Shrimps" were so named because of the periodic nuptial swarming in this river of an obscure species of marine crustacean. In but slightly altered form, the Portuguese designations were later adopted by the various seafaring nations and inscribed upon their charts from the earliest times. Not only did the name come in time to embrace the neighboring coast, but the hinterland as well; and Kamerun became the official name for the former German colony, of which the French and British version is Cameroon.

The crustacean in question is the little shrimplike estuarine burrower, *Callianassa turnerana.* When this species swarms the number of individuals that rise to the surface of the water and swim about is literally incalculable. This prodigious swarming takes place in August, at approximately three-year intervals, and endures from three hours to a week or ten days, during which time all work is suspended by the native tribes in the region and a grand fête declared for the fishing and eating of this delicacy. During the swarming great stretches of the estuaries turn white with the pale-colored crustaceans. They suggest the silver horde of Pacific salmon running upstream on the inevitably fatal spawning journey. The *mbeatoe*, as the natives call the shrimp, disappears as abruptly as it came.

The natives do nothing during these triennial swarms except fish and feast on *mbeatoe*. All tribal differences among those resident on the coast are forgotten during the grand occasion. Social distinctions, too, are laid aside, and the most lowly may insult even the chief among the notables if he be so minded. As Dr. Monod, to whom I am indebted for the genesis of the greater part of this tale, relates, public confessions of personal ills or maladies and even of one's connubial troubles, seem likewise to be in order. But two stern prohibitions also prevail. Any one challenged to give his name may be slain at once if he does not respond to the third demand for such information. This is solely as a precaution against spies and against attacks from the more warlike inland tribes who have in the past taken advantage of the "shrimp week" to perpetrate disastrous raids on the coastal populations. The other taboo concerns the women, for only men may take part in the actual fishing of *mbeatoe*.

The procedure is somewhat as follows: The men wade out waist deep into the water with baskets and canoes. Every dip of the basket in the water means a full take of shrimp. The fishery appears to be prosecuted only in

the evening and at night, and, failing moonlight, each of the many boats is provided with its flaming fagot.

In spite of the intense excitement prevailing, the entire performance is conducted with religious fervor and with all due regard to precedent. The natives maintain a crude but rhythmic cadence in the dipping of the baskets, keeping time with a barbaric chant of "*hou hou! mbeatoe! hou hou mitoke mikamba! hu hu! corine mbeatoe!*" varied at intervals with direct address to the personification of the shrimp as "the man of the river." Such vast quantities of the crustaceans are consumed that great piles of the discarded carapaces accumulate in all directions, and, rotting under the tropic sun, produce a most awful stench. One wonders whether after all it was not the smell rather than the swarming of the shrimp that lingered longest in the memories of the Portuguese navigators who gave the place its name.

CHAPTER V

CRUSTACEAN CONVERSATION

Crustaceans are probably not the inarticulate beings we take them to be. From such instances as we have of their ability to communicate one with another, it is entirely reasonable to believe that sound production in them may be a much more widespread phenomenon than it is now thought to be.

Some of the Crustacea are very "garrulous" and make their presence known at the slightest provocation. One has only to walk over a coral reef where the "pistol crabs"—alpheid shrimps—abound at low tide to be bombarded from all sides by sharp reports. Of what use this noise is to the tiny makers is difficult to tell. Perhaps it is a warning signal from one animal to another, or possibly the little shrimp just can't help making it when he snaps shut the larger and more powerful of his two claws. The pincers of these crustaceans are markedly dissimilar, and the larger, the "popgun" so to speak, is quite peculiarly built and usually appears very much distorted. The movable finger is provided with a little plug that fits snugly in a tubular pocket in the opposed fixed finger (Fig. 38, upper). The withdrawal of this stopper, like the sudden withdrawal of a tight-fitting cork, is said by many authors to be the cause of the sharp reports. But my own observations, as well as those of others, indicate rather that the sound is produced by the closing of the fingers one against the other. With such force do the two fingers come together that if a hard object, such as a piece of wire or a dissecting needle, be held in the open claw,

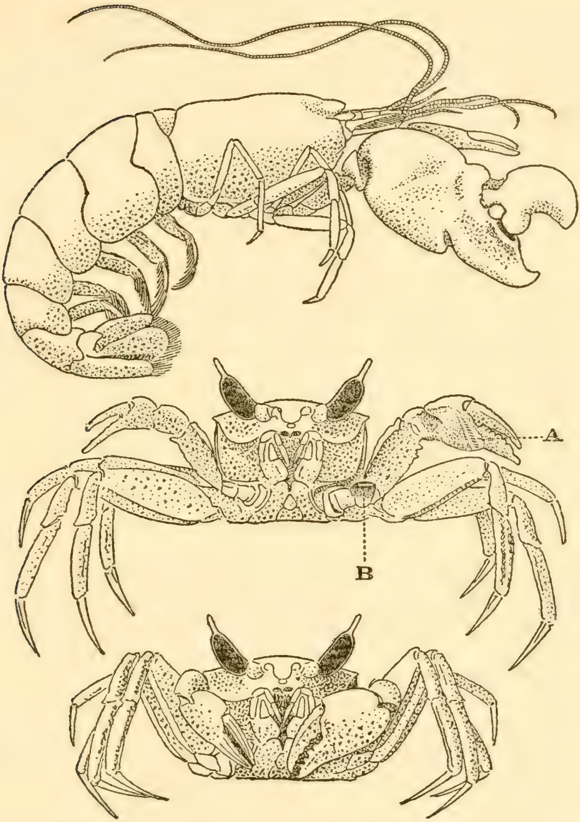


FIG. 38. "Speaking" crustaceans. Upper, pistol crab (*Crangon* [*Alpheus*]) several times enlarged. Plunger and tubular socket can be seen in big claw. Middle, ghost crab (*Ocypode*), showing ridges on the big claw (A) which it rubs against the boss (B) when the claw is drawn in as in lower figure

one or the other finger is shattered by the force of the blow. One of these alpheid shrimps in a glass dish or small aquarium can make you think some one is giving the glass a smart blow with a tack hammer; and even though you know the cause, you can not resist the feeling that each report spells the end of that particular piece of glassware.

Sounds of another kind are produced by our common East Coast mantis shrimp, *Chloridella empusa*. It makes a vigorous rasping noise by rubbing the uropods against the under side of the telson. This peculiar form of stridulating is also found in an Indian shrimp described by Alcock. In this shrimp the edge of the telson and the inner edge of each of the inner branches of the uropods "are finely burred like a rasp, so that when they are rubbed upon one another a soft trilling sound, like the subdued note of a grasshopper, results."

In such mechanisms as these, apparently designed specifically for sound making, we have stronger indications than in the "popguns"—which may be purely accidental and incidental—that crustaceans actually communicate with each other.

The Florida spiny lobster also produces a good loud noise, comparable to that of a moist finger rubbed against a window pane. It does this by rubbing a specially developed flap on the antennules against the keeled orbital margin.

Dr. Mary J. Rathbun has recently called attention to the fact that the heavy-bodied stone crabs of the genus *Menippe* are well provided with vocal organs, which vary according to the species (see Plate 69, upper); and in the absence of other criteria—at least in the American forms—each species may be distinguished by the vocal organs peculiar to it. These organs, in general, are variously organized patches of striae on the inner surfaces of the chelae that play against tubercles on the carapace. It is plausible that many of the stone crabs are more

given to articulate utterance than has heretofore been suspected, a statement that is borne out by observation of a relative of *Menippe* among the xanthid crabs—*Pseudozius bouvieri*. This fellow rubs the wrist, or carpal joint, of the cheliped against the edge of the carapace to generate a note akin to that produced by a grasshopper when it fiddles over its wing covers with the roughened thighs of its hind legs.

A simple row of tubercles or granules scraped by a ridge of no complexity might appear to be limited to the production of but one sound or tone, but Colonel Alcock seems to have proved otherwise. He discovered that the "ghost" crab, *Ocypode macrocera*, was capable of at least three tones. Although this species occurs in battalions, each individual has its own burrow, which it holds to be inviolable; and no other *Ocypode* ever voluntarily enters it. These crabs have to be on the constant lookout for attack by kites and jackals, and so it is essential for the continuance of the species that each individual should at all times have unimpeded access to his own home. As Colonel Alcock writes:

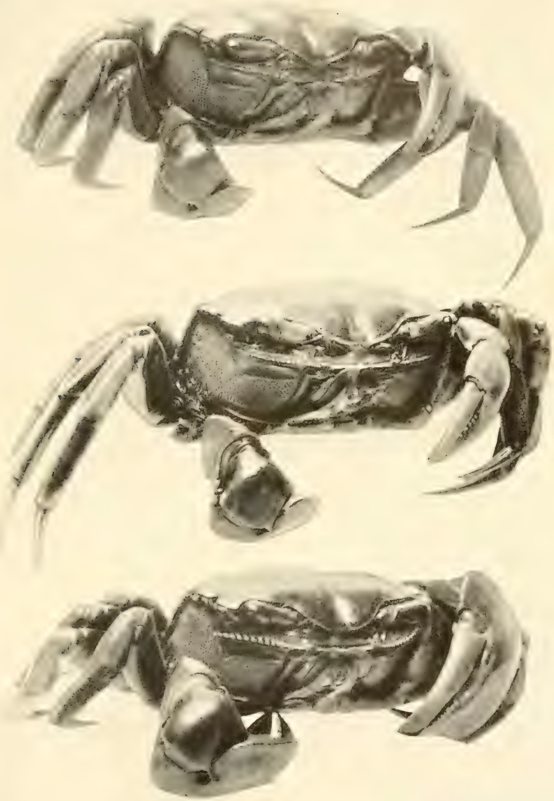
> . . . if many crabs make a practice of crowding into one small burrow they would certainly run the risk of being suffocated, if not crushed to death outright. It seems probable, therefore, that it would be advantageous to the species as a whole if the rights of property in burrows were rigidly respected, and if each individual member possessed some means of giving notice that its burrow was occupied—or, as Mr. Stebbing has expressed it, that it was "not at home" to callers; and I think that this consideration gives us a clue to the use of the stridulating mechanism.
>
> The sounds can be heard, and their effects seen, by forcing one crab, which we will call the intruder, into the burrow of another, which we will call the rightful owner. The intruder shows the strongest reluctance to enter, and will take all the risks of open flight rather than do so, and, when forced in, he keeps as near the mouth of the burrow as possible. When the rightful owner discovers the intruder, he utters a few broken tones of remonstrance, on hearing which the intruder, if permitted, will at once leave the burrow. If the intruder be prevented from making his escape, the low and broken tones of the rightful owner gradually rise in loudness and shrillness and frequency until

they become a continuous low-pitched whirr, or high-pitched growl, the burrow acting as a resonator.

Apparently *O. macrocera* can produce at least three tones by working the inner side of the larger of the two always dissimilar claws against a row of teeth on the arm of the same appendage, "much as a man might rub one side of his chest with the palm of the corresponding hand." On the inner side of this crab's chela is to be found the secret of the tones of *Ocypode*, in the shape of a "keyboard," or a row of five transverse striae (Fig. 38, lower). A closer examination discloses that this corrugated keel "is somewhat low, flattened above, with the lower half of its surface moderately broad, the upper half tapering to the end. Near the upper end this area has rather coarse ridges moderately distant from each other; from the upper end downwards to beyond the middle the ridges become gradually finer and more closely set, and on the lower third they are very fine, and the impressions between them extremely narrow." Thus the keyboard has three distinct regions, like a fiddle with three chords; and with the variations and modulations that not only the angle but rapidity of motion may invoke we should realize that *O. macrocera* may have a far greater range of articulate sounds than the unaided human ear is able to appreciate.

In a group of crabs of the genus *Helice*, found in China, the keyboards vary in coarseness of striation in different species, as can be seen in Plate 54. These differences in their keyboards surely indicate differences in tone of the sound they produce.

In southeastern Asia and the East Indies there occurs in countless numbers a little globular crab, *Dotilla myctiroides*. These crabs go through group evolutions smacking of military maneuvers. The instant danger threatens they disappear in the moist sand of the beaches, which they use as parade grounds. At a little distance the crabs seem to be intensely blue with bright yellow legs, and their



Varieties of the Chinese land crab (*Helice tridens*). Note that the sub-orbital stridulating ridge of the upper crab is fine-toothed, that of the middle crab, medium-toothed, and that of the lower, coarse-toothed. Each undoubtedly produces a different tone

apparently ceaseless maneuvers give to the beach the appearance of an endless shimmering, iridescent sea. But on closer approach, the gaudy spread of pigment resolves itself into myriads of little crabs climbing over one another, three or four deep, in their anxiety to sink from sight as the enemy approaches. The entire performance is accompanied by a continuous wave of sound—a rustling, swishing sound, as of the wind blowing through dry autumn leaves that still hang on the trees; now softer and now louder, as the innumerable host rushes here and there or wheels about. As long as the crabs are in rapid motion the sound continues, only to be stilled with their mystical disappearance.

This massed volume of sound is produced by the brushing of the joints of the ambulatory legs against the edges of the carapace, and, more particularly, against a roughened convoluted area on either side of the much inflated body, which seems to have assumed this shape for the express purpose of allowing the legs to make the sound peculiar to these crabs by brushing over the specially modified lateral walls of the carapace. Here we seem to have an instance of purposeful sound production to give warning of change of movement to all members of the corps.

The fact that many investigators seem to have failed to find any sense of perception that might be called auditory in Crustacea is no proof that these animals do not appreciate sound and sound variations, or that they do not communicate with one another by means of sound. It may be that both in our reasoning and our experimental investigations we fail to "speak their language." The many and varied devices with which Crustacea are equipped for producing sound—or merely noise, if you prefer—and the modulations of tone of which many of these devices are capable surely have a significance that is far from being properly understood.

Carl Aurivillius, in his detailed study of sound produc-

tion among crustaceans, finds reason to believe that it is a form of speech in these animals. He bases his opinion on the fact that in most of the crabs in which the stridulating apparatus is most highly developed—such as the ocypodes—the meral joints of the legs are compressed, straight-sided and rather thin and poorly calcified (Fig. 39). The

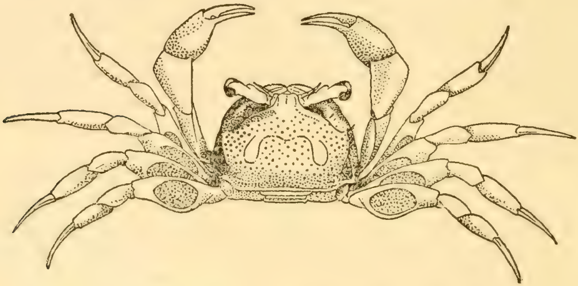


FIG. 39. Australian crab (*Scopimera inflata*), showing tympani as dark oval spots on legs. These may represent organs of hearing. After Kinghorn

very nature of the fragile walls of these joints renders them sensitive, sound-receptive diaphragms, capable of performing the function for which they were evidently intended. Why else should they be so developed in these crabs? Nor must we overlook the fact that not a few crabs are provided with curious feebly chitinized, more or less membranous areas, which, even if located on the meral joints of the ambulatory legs, are inescapably suggestive of a tympanic function. As strangely placed as these "ears" are, they occupy a no more unique position than do the auditory organs of the grasshopper, which are found paired on either side of the first segment of the abdomen.

Crustacea would have as many uses for sound production and perception as have other animals that hear and

"speak": To keep individuals of the same kind or species together or in touch with one another; to warn of enemies and of danger by sudden alarm or sharp sound; to escape the clutches of attacking animals or frighten away intruders or unwelcome visitors; to secure inviolate the "sanctity" of the home; to emit a love call or song, as some fiddlers, at least, may do; to express anger or annoyance; or to send out from time to time a cheery "All's well."

We have still a long way to go before the last word can be said on the "speech" of shrimps and crabs.

CHAPTER VI

LIGHT AND COLOR IN CRUSTACEANS

Luminescence

Luminescence in the sea, with its beauty and mystery, involves one of the most fascinating problems of zoology and biochemistry—the production of cold light. Many theories have been advanced to account for it. Even Benjamin Franklin made it the subject of his penetrating curiosity. He believed that it was due to electric sparks generated by friction among the salts of the sea.

Much of the most productive research on the subject has been done on the marine "firefly" of Japan, an ostracod, *Cypridina hilgendorfi*. This small crustacean gives off brilliant rich-blue sparks of light when disturbed and can repeat the act many times. A few individuals of this species shaken up in a tube of water give easily enough light to read by, and if alcohol is substituted for water the light may persist as long as fifteen minutes. Indeed, so powerful are the substances that engender the light that in water a proportion as minute as 1 part in 1,700,000,000 parts of water will still give a visible light. The ostracods themselves, as well as the light-producing materials they contain, may be dried and preserved almost indefinitely without impairing their luminous qualities.

I suppose not less than a dozen ostracods are known to possess this gift of luminescence. The color of the light they emit varies: in some, like *Cypridina*, it is an intense blue; in others it is bright green or yellow, or a combination of both. The luminescent secretions of ostracods are produced by special glands, and some of them can store

up considerable quantities of light. It is supposed that the purpose of the secretions is to frighten away enemies. This theory is in keeping with the ostracods' habit of shunning any light that would render their own less effective. During the day they lie concealed, and on moonlight nights they are hard to find. Even the electric illumination of water fronts where they occur inhibits their activities. Brilliantly luminous ostracods will at times be left stranded, by the wash of the waves, on the beaches of the Dry Tortugas (Florida); and two species are found in the shallow water of Montego Bay, Jamaica.

In suitable seasons in San Francisco Bay every dip of boat oars at night stirs up much shimmery white gold, for which certain copepods are responsible. Not less than seven known species of these crustaceans give off light from organs distributed over the body. *Pleuromma abdominale*, a cosmopolitan species, may have as many as eighteen such organs. Two species of luminescent copepods are known from the coasts of Norway, Spitzbergen, and north Greenland, and Nordenskiöld writes of luminescent copepods cast ashore on the Arctic coasts as follows: "Very singular is the impression experienced in walking on a cold, dark, winter's day (with the temperature nearly at the freezing point of mercury) on snow from which on all sides shoot at every step sparkles so vivid that sometimes one is almost afraid of seeing one's boots and clothes catch fire." The sparkles referred to in the passage just quoted emanate from live copepods, although of course, under the circumstances mentioned, they can not be free-swimming.

As we go higher in the scale of crustacean life, the light organs change from the simple glands of ostracods and some copepods to organs of greater complexity, and at times these will have a lens as well as a reflector to intensify the light they emit. In the euphausid Malacostracans we find organs of this type so complex that they were long considered eyes, and that they had light-produc-

ing functions was not realized till a comparatively late date.

Many species of luminous Crustacea are pelagic forms, such as our common New England coast species *Meganyctiphanes norvegica* (see Plate 32), the individuals of which, during midsummer, swarm along the coast, flashing as brilliantly as so many fireflies. Other species live at greater depths. Colonel Alcock had the good fortune to bring up alive two species of prawns—*Heterocarpus alphonsi* and *Aristeus coruscans*—from a depth of 561 fathoms in the Indian Ocean. Both sexes of *Heterocarpus* "poured out copious clouds of a ghostly blue light of sufficient intensity to illuminate a bucket of sea water so that all its contents were visible in the clearest detail." This light emanated from the prawn's anterior region.

Professor Ulric Dahlgren states that the luminous substance in these shrimps is "secreted by a large number of glands of the common integumental type found in crustaceans. These glands pour out the secretion from hundreds of tiny, hairlike ducts opening on the under side of the head from around the mouth and from the inner sides of the bases of the limbs on the anterior part of the thorax. This very small amount of secretion is then mixed with the strong stream of water, augmented for the occasion, that comes from the respiratory chamber and is thus carried out in the copious clouds of light that have been described."

Special light-emitting organs in animals are called photophores. There is one shrimp, *Sergestes challengeri*, which when full grown will show as many as a hundred and fifty of these points of light, and we can well imagine that such a crustacean in full illumination would look like Coney Island on the move. No luminous true crabs have as yet been recorded.

As to the whys and wherefores of this light-producing power in marine animals, the late Professor Doflein has

summarized as follows the various theories that have been advanced: To attract prey; to attract other individuals of the same species in order to form and maintain swarms; to attract the opposite sex; to frighten off a pursuing enemy by a sudden flash of light, or to confuse him with a luminous mist while the pursued escapes in the dark; and possibly, in the absence of other light, to illuminate objects the animal may wish to see.

Dr. Stanley Kemp, in reviewing these theories, remarks:

> It is evident that these suggestions will not account for every case which can be found; the photophores in the roof of the branchial chamber of *Sergestes* remain inexplicable.
>
> The vast majority of marine animals which possess photophores live at the surface or at intermediate depths and never occur on the bottom. . . .
>
> Many of the higher marine animals live on the sea-floor at depths to which no ray of sunlight can ever penetrate, and, though they possess well-developed eyes, are themselves, for the most part, without any special illuminating apparatus. That light exists at these depths seems almost certain. It is probably fairly plentiful in regions thickly populated by Coelenterates, and the excretions of numerous animals of a more highly organized nature have been found to be brilliantly phosphorescent. The restriction of photophores to species living in midwater seems only explicable on the theory that there is a comparatively plentiful supply of light on the bottom itself.

The production of light in these animals, as numerous researches have amply demonstrated, is brought about by the reaction, in the presence of oxygen and moisture, of one photogenic substance—luciferase, which is secreted in special gland cells—on another—luciferine, which is found throughout the tissues of the body and in the blood.

The most remarkable feature of these essential substances is that they may be dried, extracted with ether, or treated in various other ways without affecting their power of producing light. The process, then, is quite independent of the animal body in which the substances were produced and therefore is a physicochemical phe-

nomenon. If kept dry, the substances will retain their light-giving properties for months and even years.

Not all crustacean phosphorescence is produced at the will of the animal. There is sometimes tragedy involved in the luminescence of things marine. One of the unfortunates among the illuminated is *Talitrus*, the amphipod beach hopper, which appears to be subject to infection by luminous bacteria. Without any impairment of their luminous power, the bacteria seem to thrive and flourish within the alimentary tract of the amphipod. Eventually the helpless host succumbs to the inroads of this internal blaze of glory. Other amphipods, if not already infected, may in turn become so if, as is often their wont, they eat their fallen brethren. Such infection is inevitably fatal.

The luminescence of aquatic creatures has usually been associated with a salt-water or a sea-beach habitat; but recent observations have shown that a Japanese fresh-water shrimp, *Xiphocaridina compressa*, glows with inward light just as does the marine amphipod *Talitrus*, and does not long survive the infection which produces it. Even healthy shrimps of this species, when placed in fresh water in the laboratory, became luminous in one or two days and died after remaining luminous for several hours. The causative bacterium was described by Dr. Y. Yasaki as new to science, and probably the first luminous bacterium found in fresh water. The light it produced was so intense that that emitted by twenty or thirty of the luminous shrimps in a test tube was sufficient to read by in an otherwise dark room.

There was a time when all marine luminescence was ascribed to bacteria; but nowadays, as has already been shown, it is known that bacteria are not responsible for this quality in all sea animals that possess it. There are certain fish and cephalopods which have special organs, or culture chambers, for carrying stores of this bacterial light without harm to themselves. Some make use of it

in screening their escape by a mantle of light—paradoxical as this may sound—and others as a lure for food.

Light is a most efficient means of attracting all kinds of animals and is employed wherever feasible by the careful and thorough collector of marine organisms. Fishermen since earliest times have used torches and lighted fagots for attracting their catch, and this method is still extensively employed in many parts of the world.

Color

The remarkable phenomenon of light in Crustacea finds what is almost its peer in certain manifestations in them of another phenomenon—that of color. Many crustaceans, like some other animals, seem able to change their color at will.

The shrimp *Hippolyte varians* has this gift to a high degree (Plate 55). Any number of individuals of this species will rest upon red or green or other-colored seaweed and be practically invisible even to a very close observer. It is true that the facility with which they change from one color to another seems to vary according to their age. A very young one can change from red to green—to match a green background—in a few hours, but such a change takes longer and longer as the animal grows older. It appears that early in life these shrimps make their choice of habitat and color and later tend to abide by it. Those that make their home upon the green weeds take on a livery of like color, and those living among the red or the brown weeds dress themselves accordingly. But one may force an older individual to change color by placing him in quite a different environment. When this is done, with few exceptions the shrimp will respond in time; and thereafter it is easier for him to reverse or change color. But one change all shrimps, whether young or old and whatever their fixed color, make every night: they turn blue. Quite the reverse of rational humans, *Hippolyte* turns night into day for feeding and repose. He

spends the hours of sunshine resting and sleeping and in the vegetative manufacture and storing up of fat, and it is during the day that his wonderful mimicry of the background takes place. *Hippolyte's* palette carries but three pigments—red, yellow, and blue; but by expansion and contraction of the chromatophores, these primary colors are wonderfully suppressed and intermingled as required.

Victor Bauer has devoted much study to the crustacean life of the Mediterranean meadows of sea-grass. Among the roots and root stalks of the "grass" he found concealed the tubes of the tube-building amphipods; and in the sandy stretches between the patches of vegetation were Portunid crabs, resting on or half buried in the sand, but speckled and mottled so like the pattern on the sandy bottom made by the play of light and shade as to be well-nigh indistinguishable from it. On the leaves of the grass he found isopods and shrimps, which followed even the seasonal change of the sea grass in their choice of livery: in the spring, when all the new shoots were fresh and green, so were all the crustaceans that lived in their shelter or upon them; but later, as the leaves turned brown, the crustaceans did likewise.

There is a little crab in Florida of a dull-red color—*Thoe puella*—which so mimics some of the stony red seaweeds incrusting the underside of rocks that you can not visually distinguish one from the other unless the crab moves. And there is a well-known amphipod, *Hyperia galba*, that is quite as adept in the art of mimicry. It travels around attached to the transparent bells or umbrellas of jellyfish, and at such times it is lacking in color in order to match closely its means of transportation; but when free from the jellyfish it rapidly takes on a yellowish or brownish tone, more like the sea bottom on which it happens to come to rest.

Color is protective—no doubt about it—when it matches and merges with its background or environment. The speckled birds of the sea beach are well-known ex-

PLATE 55

A few of the many phases of protective coloration exhibited by the prawn *Hippolyte varians*. This species hides by day and feeds by night, when, as shown in the inset, it turns blue. By E. Cheverlange

amples of protective coloring, and crustaceans of varied habitat take their place with them. Yet investigations tend to show that protection is not the primary function of color in some animals at least. Professors Keeble and Gamble ran down one hypothesis after another in an effort to account for the presence of the color-bearing chromatophores in *Hippolyte* and to discover their function and the reasons for their changes and behavior in different individuals of the species. They found a fat-synthesizing function paramount. Resting by day, as these prawns do, on the sea plants of their surroundings, fat is produced under the influence of the sun's rays. And this hypothesis is not so difficult of proof as one might think. When animals are starved in the dark, the fat globules—along with the pigments in the chromatophores—become gradually depleted, just as green plants get pale in the absence of light; but "if such lean specimens are taken out again into the light at the end of a fortnight, they will in the course of a single day show not only a fatty skin, but a far denser accumulation of fat than is to be seen in a freshly caught prawn."

Let us pursue for a little way this comparison of the reaction to light in plants with the same reaction in animals. As we go down in the scale of life we find the differences between animals and plants disappearing so fast that, even as we look, their lines seem to run together and, for all we know, merge into one: at the lower end of the scale, plant is animal and animal, plant. Compare any comprehensive work on zoology with one on botany and you will find some of the same organisms treated in each. Therein, perhaps, lies the clue to the trail unveiling the mysteries of animal coloration.

The secret of all the wonderful color display of flowers is chlorophyll, the ordinarily green substance present in nearly all plant life. Chlorophyll is the most wonderful synthesizer known to man. Under the influence of sunlight it reorganizes and combines simple inorganic sub-

stances derived from soil and air and water to form organic foodstuffs.

Investigators now are finding a chlorophyll-like substance at the basis of color in animals as well as in plants. This substance, which we may call animal chlorophyll, responds to chemical and spectroscopic tests just as plant chlorophyll does, and to all intents and purposes appears to be the same. The color of any simply organized green-hued animal, as of any green plant, is due to its chlorophyll-containing chloroplasts. Some students of the subject claim that such animals have the power of building their own chlorophyll, others that they take the substance from the plants they consume and incorporate it into their own bodies in such a way as to make use of its food-manufacturing properties. The illuminating researches of Dr. John F. Fulton indicate that many, if not most, of the lower pigmented animals derive their color from an algal pigment—the result of an infection from without which thrives in the animal host. The fact that in certain cases, at least, the algal pigment is ingested would explain the means by which the chlorophyllous substances get into the body of the animal.

The various colors found in animals—red, yellow, and blue, alone or in combination—all seem to have the same basis; and that basis is the same as the basis for the various colors found in plants. Doctor Fulton even concludes: "Strong evidence exists that the respiratory pigment haemoglobin [in our own blood] is derived both phylogenetically and physiologically from chlorophyll"! The exclamation point is mine. Fulton has also said, with reference to Crustacea, that "the enterochlorophyll found in the liver of many crustaceans and mollusks is of vegetable origin. There is evidence that it is the base from which the animal synthesizes many other of its pigments, including haematin."

It appears that starches are best synthesized by chlorophyll green, whereas fats and oils are most efficiently pro-

duced by the yellow and red organic pigments, such as carrotin. At least we find this to be true in the plant world, especially in the carrot, from which carrotin has derived its name. As Professor Gamble has remarked: "Nothing is more common than for oil to assume a yellow color, or for the seed coats of some plants or the tubers of others [where such fatty stores abound] to become yellow or red."

As a fitting close to this absorbing subject of color and its relation to chlorophyll and sunlight in animals and plants, let me remind you of the curative effect of sunlight on human beings afflicted with rickets. It would seem that in some subtle way our bodies, too, are able to manufacture some curative substance or substances under the influence of sunlight, in much the same way as *Hippolyte* manufactures fat and the plants manufacture oil and starchy compounds.

CHAPTER VII

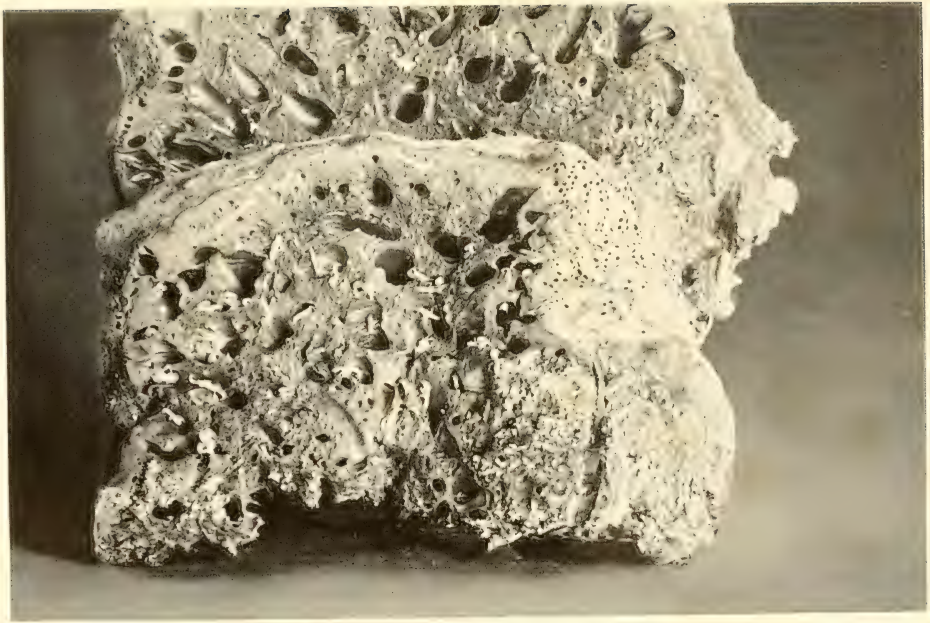
CRUSTACEAN ARTISANS AND THEIR HOMES

The crab and such of his crustacean relatives as are bottom- or shore- or land-dwelling types are householders, each after his own manner. Some of these fellows are builders and display marvelous ingenuity in fashioning, with their claws and legs, the recalcitrant materials of their environment into homes. Others are lazier but no less shrewd, for they preempt mollusks' shells or other suitable retreats and thus acquire their homes at no cost to themselves.

This record takes no account, of course, of the endless variety of Crustacea that swim or are wafted about in the water for the length of their days. For them the word home is meaningless.

The simplest type of shelter among crustaceans is, perhaps, that made use of by the edible crabs of our coasts, which bury themselves in the sand or mud either for protection or to conceal themselves in order to surprise their prey. On weedy or rocky shores, many crustaceans will hide among the seaweeds or in the rock crevices. The number that seek shelter in other living animals or in imperishable animal remains is legion. Hermit crabs are found in mollusk shells the world over. Tiny shrimps, like the pontonids and synalpheids, reside within the canals of sponges, making of them veritable marine apartment houses (Plate 56). Other forms nestle down on coral polyps, allowing the latter to grow up around them to form a nest. Often, as the growth of their host continues, they find themselves unable to escape and so become prisoners for life. Still others live in worm tubes

PLATE 56



Shrimps (*Synalpheus brooksi*) living in the canals of the loggerhead sponge. Photograph by A. S. Pearse

of various descriptions. The California sipunculid worm *Urechis*, like the parchment worm of our east coast (which builds a U-shaped tubular dwelling), gives shelter to certain crabs, to say nothing of other animals (Fig. 40). All

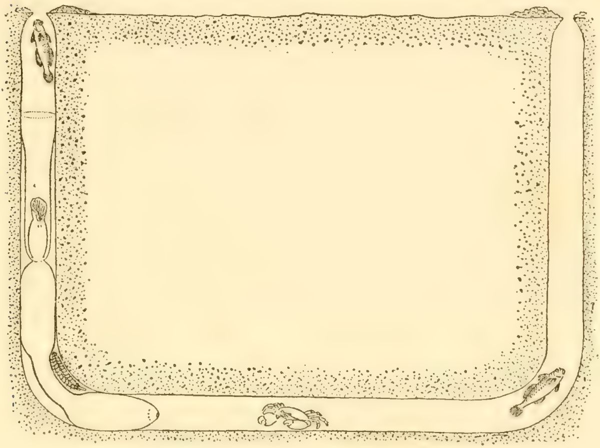


FIG. 40. Slime-lined burrow excavated in the sand by the sipunculid worm *Urechis*. The worm (lower left) pumps a current of water through its tube, catching food particles in a funnel of mucus. The food is plundered by both the crab (*Scleroplax*) and the small worm (in the left corner). The fishes are seeking shelter. After Fisher and McGinitie

the lodgers partake of the food particles carried into the tubular housing by the currents set up therein by the worm. As in so many partnerships of this kind, direct benefit to the host still remains to be demonstrated; but for the commensals the advantages of the association are many and obvious, and not the least of them is the prolonging of the breeding season in these species of crabs.

Edible mollusks in all parts of the world are infested by commensal crabs. At Hampton Roads, the headquarters

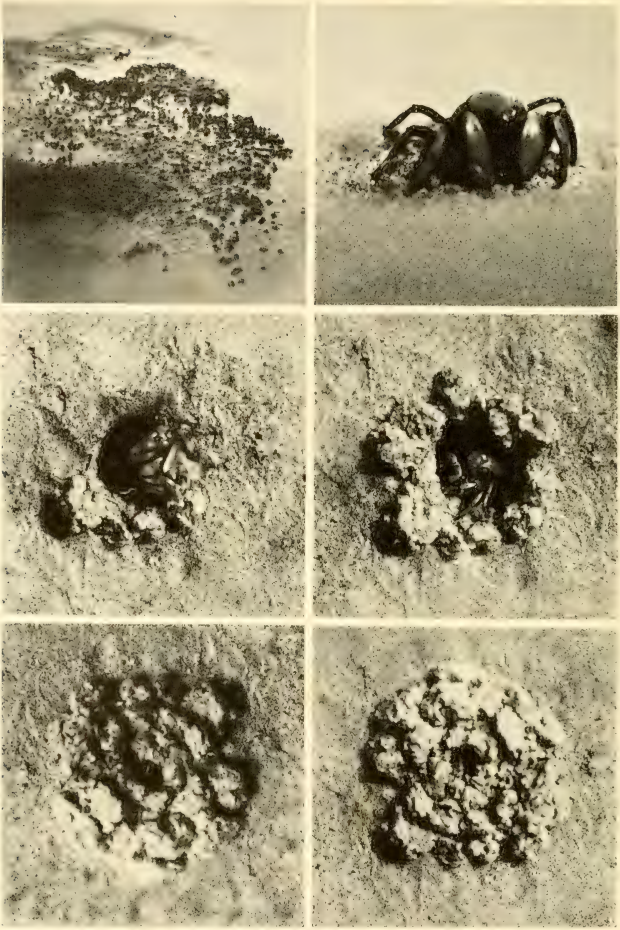
of the Chesapeake Bay oyster industry, it is possible to get the little oyster crab in great quantities, that is, the female of the species. The male is seldom seen. The female, sheltered and sedentary, has become quite soft of shell and appears rather helpless when removed from her abode, which under ordinary circumstances she seems never voluntarily to forsake. Not so with the male. He visits about from shell to shell, calling on the ladies. He is, moreover, hard of body and rounded, so that an occasional nip resulting from the unanticipated closing of a mollusk shell he is about to enter or leave will tend to squeeze him in or out with no more harm than the loss of a limb or two—a trifling matter in the life of a crustacean.

Copepods and crabs are not the only crustacean commensals; a host of shrimps have also adopted this style of living. But although it is rare to find more than one crab in a shell—and that one always the female—the two sexes in many species of shrimps are quite inseparable.

But the crustacean home making we have been describing is like renting a furnished apartment with hotel service. The situation is quite otherwise with the crustacean builders. Land crabs are energetic excavators wherever they occur. Fiddler crabs especially are well known for their digging propensities, and they usually spend each high tide safely immured in a retreat constructed for the purpose and furnished with a bubble of air for respiration. The fiddler is enough of a builder to give the ground upon which he plans to make his home a preliminary testing out with his feet. If it has the right feel he begins operations. As he digs he scrapes out the sand, rolls it into pellets, cradles it in some of his feet, and deposits it at the mouth of the hole or burrow—unless this interferes with the work, in which case he moves it away.

The depth of the burrows is remarkably uniform in a given area and has been found to be conditioned by the depth to which the moisture penetrates the sand. The crab often plugs the entrance with a "cork" of sand or

Handiwork of the sand bubbler (*Scopimera inflata*). Left, pellets and trenches made by the crab when feeding. Right, a twelve-inch burrow with crab at the bottom. Courtesy of the Australian Museum



How the soldier crab (*Mictyris longicarpus*) digs in. Upper left, an army of soldier crabs on the march. Courtesy of R. P. Cowles

mud and sits safely ensconced within for as much as several days at a time. Invariably as the tide rises he closes the burrow tightly to imprison the air contained in the end chamber. As far as has been ascertained, the fiddler is without knowledge of the periodicity of the tide other than that he is aware of its rise and fall by the degree of moistness of the walls of his burrow. It has been observed that crabs on the beach frequently visit and revisit their burrows for no apparent reason, but it may well be to observe the state of the tide indicated by their condition.

Continued existence for most Crustacea is probably at the price of eternal vigilance. The fiddlers and other architects of beach homes well illustrate this vigilance. Coming out of his burrow with a load of sand and pebbles, the fiddler stops at the circular front door and carefully surveys the surrounding terrain with his stalked eyes, which are articulated periscopes, to make sure that the coast is clear before he will venture further.

Like human artisans, the fiddlers must have their "sport," it seems. The most amusing incident of this sort concerns two male fiddlers of medium size that Doctor Pearse had watched running about for perhaps half an hour over an area twelve to fourteen yards in diameter. "They kept close together and acted like two mischievous sailors ashore. The tide was coming in rapidly, and in their rambles the pair came to a place where a large slow-moving [crab] was carrying a plug to close his burrow. They waited until the plug had been pulled down over the owner, then [one of them] went to the hole and removed it; and as the outraged owner emerged the plug remover and his mate scuttled off toward the former's burrow."

Most naturalists believe that the waving of the large claw of the male (see Plate 50) is an amatory gesture to attract the female—to show the lady of his affections that he is a "crab among crabs." In a number

of species the great chela is very beautifully colored, but whether the color as well as the motion exercises a potent influence on the sensory perceptions of the female has been questioned. Quite recently Dr. J. Verwey suggests that the claw is waved to warn off intruders from each crab's own particular eminent domain. His point seems well taken, for did not the various males keep all other crabs at sufficient distance there would be not enough food or "grazing" ground about the mouth of each burrow to nourish the many individuals we always find crowded together in every fiddler community.

Ocypode, the ghost crab, often digs a burrow as much as four feet deep in order to get down to moist sand, after which he continues it more or less in a lateral direction as a tunnel. Fiddlers seldom go deeper than a foot. The *Ocypode* will sometimes have a second entrance or exit to his home, though he seldom uses it as such. It has been suggested that this is for ventilation—a very intelligent provision, if true. After stocking his burrow with food, he has been observed to draw two loads of sand into the entrance, thus practically closing it but leaving the distal joints of several of his walking legs outside. With these he carefully tamps down the plug and finally quickly draws them in, leaving sometimes only a very small hole and sometimes none at all. By this means the entrance to the burrow is very effectually concealed.

Professor Cowles reports having seen crabs of this genus lying on their backs in their tunnels digging away at the roof, and he surmises that this is probably the manner in which the vertical passage is started.

It is difficult to leave the subject of burrowing crabs without a few words about the habits of the sand bubbler and of the little soldier crab of Australasia.

The sand bubblers occur in great numbers and make their presence known by millions of tiny pellets of sand on the beach. As the tide recedes they scramble to the surface and proceed to repair their burrows. Each one

bores a clean cylindrical hole from three to fifteen inches deep, depending apparently on the depth of the looser and more watery sand below the surface (Plate 57). This accomplished, the sand bubbler begins feeding. In the words of F. A. McNeill, "he moves sideways from the mouth of his burrow and scoops out a narrow trench with his capable little nippers. The excavated sand is then passed into the lower portion of his capacious mouth-jaws, where it is carefully sieved for its contained food-particles. It is then expelled from their upper portion and so manipulated as to form a rounded pellet. Upon reaching a definite size, the pellet is passed backwards and deposited on the beach behind the crab, which simultaneously moves on a pace outwards from its burrow. In this way a feeding trench is formed, nine to eighteen inches in length."

Mictyris, called the soldier crab because it maneuvers in great armies over the sand flats at low tide, might equally well be named the corkscrew crab, from its method of digging in. The rapidity with which it sinks from sight is almost magical. One may sometimes approach to within six yards of these crabs, but an instant thereafter an entire army will have vanished, in the manner illustrated in Plate 58. The soldier crab, which is about the size of a large cherry, accomplishes this disappearance by digging with the legs of one side and rotating at the same time, so that the digging follows a spiral.

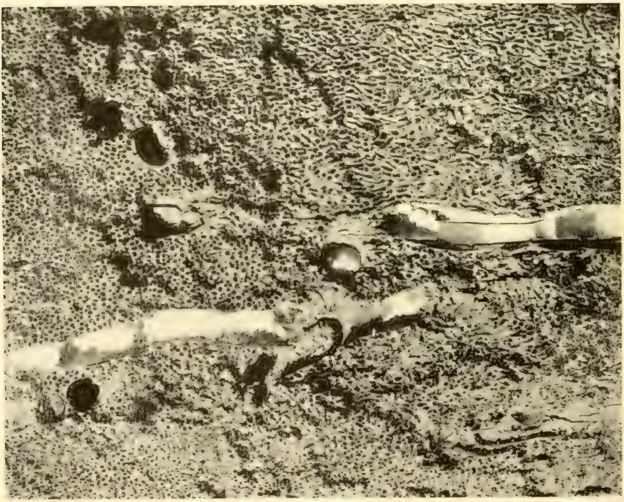
Burrow construction is common to many species of crabs and is met with in all parts of the world. It is this propensity that frequently makes crabs serious agricultural pests. But artisanship of this sort extends into other groups of Crustacea as well. Sand-fleas, beach hoppers, or scuds, dig with great celerity, in effect not unlike a dog; though, unlike the dog, they are able to employ more than one or two pairs of legs in passing the sand out behind. Nor do they cease activity when they get within the burrow, for there they busy themselves with their toilet.

They are among the neatest of small animals, forever brushing and cleaning themselves. In some of them one or another pair of the appendages is especially slender and motile and so articulated as to reach in all directions and to all extremities, as though it were built expressly for the job of cleaning, properly and carefully, every portion of the creature's body. (See Fig. 8, page 104, for similar activity in a shrimp.) These almost automatic brushes are at their busiest when the animal is otherwise at rest; and, since to do their work effectively they must themselves be kept clean, certain of the mouth appendages comb them from time to time, thus freeing them from the débris and grit they have accumulated.

In the Puget Sound region, the subterranean homes of the shrimp *Upogebia pugettensis* are certainly noteworthy structures. One such burrow found by Dr. Belle Stevens, of the University of Washington, descended to a depth of over a yard, spread laterally for a length of two feet, and had three different openings (Plate 59, upper). The construction of such a dugout requires considerable acrobatic ability. The tunnel system, at intervals of about six inches—roughly corresponding to the length of the grown animal from the tips of the extended claws to the end of the tail—has slight enlargements in which the curved animal reverses itself to carry out excavated material. The digging and the transportation of material to the surface are both done headforemost, hence the need for turning end for end during the process.

A closely related South American shrimp constructs apartment houses in rock. The material is a soft shale, to be sure, but yet sufficiently hard to require considerable chipping and flaking with a geological hammer before the interior arrangements of the shrimp's house can be observed. I have seen one such house in three planes or stories, with "turn-abouts" such as Doctor Stevens has described excavated in stone, but with this most remarkable difference—that no openings capable of permitting

Upogebia pugettensis and its burrow
Upper: Plaster cast of burrow with an occupant. Lower: Dorsal view of a male. Courtesy of Belle Stevens



Work of wood-boring isopods

Upper: *Limnoria lignorum* photographed in the act of burrowing (x 10).
Lower: Borings by *Limnoria* in untreated pile of Oregon fir.
Courtesy of C. A. Kofoid

the exit of even a half-grown animal could be discovered. Apparently the shrimps begin their homes when young and add to them as they grow, but never attempt to forsake their stony dungeons.

Crustacea also make extensive use of wood in their building operations. The wood-boring isopods of cosmopolitan distribution (*Limnoria lignorum*) construct apartment houses in wooden harbor works to shelter their teeming millions (Plate 60). They will live under what we would consider the worst kind of tenement conditions—three to four hundred to the square inch, which represents considerable crowding even for an animal no more than a quarter of an inch in length.

In Charleston Harbor, South Carolina, unprotected piling lasts on the average only two years, due to the ravages of *Limnoria*. In Key West Harbor this species will destroy an unprotected pile in even less time. Nor does this crustacean respect creosoted timber. Professor Kofoid writes: "It frequently gains entrance at a knot, abrasion, or other point of thin treatment, and works in until it reaches the untreated center of the stick. This portion of the timber is promptly destroyed and the outer treated shell left intact."

Professor Kofoid has had the good fortune to observe *Limnoria* in action. He writes that the body is so firmly held in position by the peculiar arrangement of the legs and clawlike feet that it is difficult to wash the isopod off the surface of the wood with a stream of water. In the boring process itself there is a very vigorous action of the mouth parts, especially of the mandibles and maxillipeds, combined with a slow turning of the head (Fig. 41).

Usually associated with *Limnoria* is the wood-destroying amphipod *Chelura terebrans*. Because of its larger size the amphipod excavates slightly larger burrows, but the damage it causes is secondary to that occasioned by its isopod associate.

A number of isopods of the genus *Sphaeroma* are

doughty carpenters and completely riddle large-diameter wood piling, pitch pine, and even palmetto in the course of their home building. Nor is stone construction—or destruction, if you prefer—neglected by these carcinological artisans. In San Francisco Bay extensive areas of San

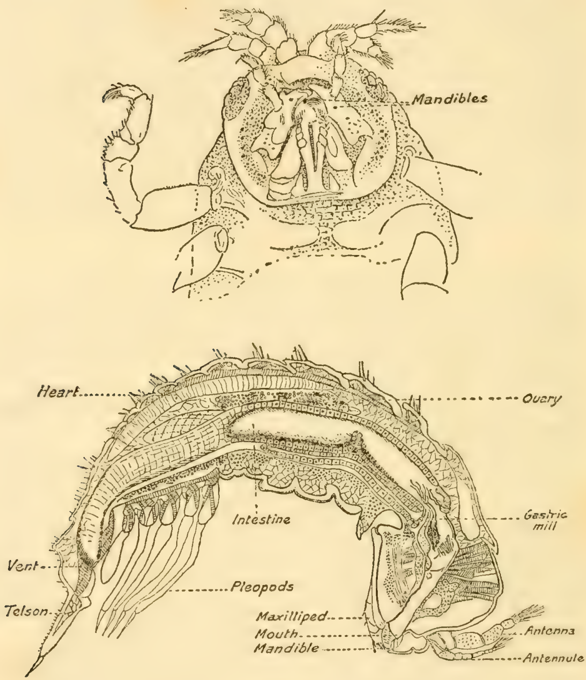


FIG. 41. Upper, ventral view of the head of the wood-boring isopod (*Limnoria lignorum*), showing mandibles which do the cutting. Lower, longitudinal section of *Limnoria* to show something of its internal organization. After Hoek, and Hill and Kofoid

Pablo sandstone and Pinole tufa have been honeycombed by the isopod *Sphaeroma pentodon* (Plate 61); and so apt have these ordinarily marsh-inhabiting crustaceans become in working masonry that when brought into the laboratory aquariums they would tackle blocks of carpenter's chalk and bite out bits with their mandibles at a lively rate. In less than twenty-four hours one specimen had bored a hole in a chalk block deeper than its own length—a matter of a quarter of an inch or so.

In Hawkes Bay, New Zealand, *Sphaeroma quoyana* made such extensive use of a clay stone employed in harbor works that the sea wall in many places virtually disappeared, and blocks of concrete which overlaid the rock sank several feet. It is said that boring crustaceans are even making use of concrete structures for residential purposes. "If this be the case," Doctor Calman warns us, "it may become a matter of very grave concern for the engineer, in view of the increasing use of reinforced concrete for harbor works of all kinds. . . . it would be well to avoid using rubble of calcareous or friable rock for mixing in concrete."

Limnoria has also been found exercising its boring propensities on submarine cables. In New Zealand, Doctor Chilton says, it was the cause of a cable failure at a depth of sixty fathoms, having penetrated the rubber insulation at a splice to the extent of admitting the sea water to the inner core of the cable.

As remarkable as these excavations and borings are, we may feel them inferior to the handiwork of animals higher in the scale of life. We have all marveled at the skill displayed in the construction of the weaver bird's nest, but such avian tailoring is easily matched by the "needlework" of certain of the Crustacea. There is a shrimp, *Crangon* (*Alpheus*) *pachychirus*, that stitches tangles of seaweed together to construct branching tubes ten to twelve inches in length and three-fourths of an inch in diameter, usually with a somewhat larger chamber in one

end. The alga used is fine and threadlike and grows in dense mats. The shrimp lies on his back in some convenient furrow of these naturally interlaced mats and with his pair of slender chelate second legs pulls together the edges of the furrow (Fig. 42). He thrusts one of these legs through one edge of the mat like a needle and, catching a

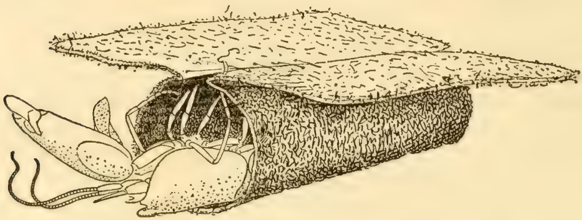
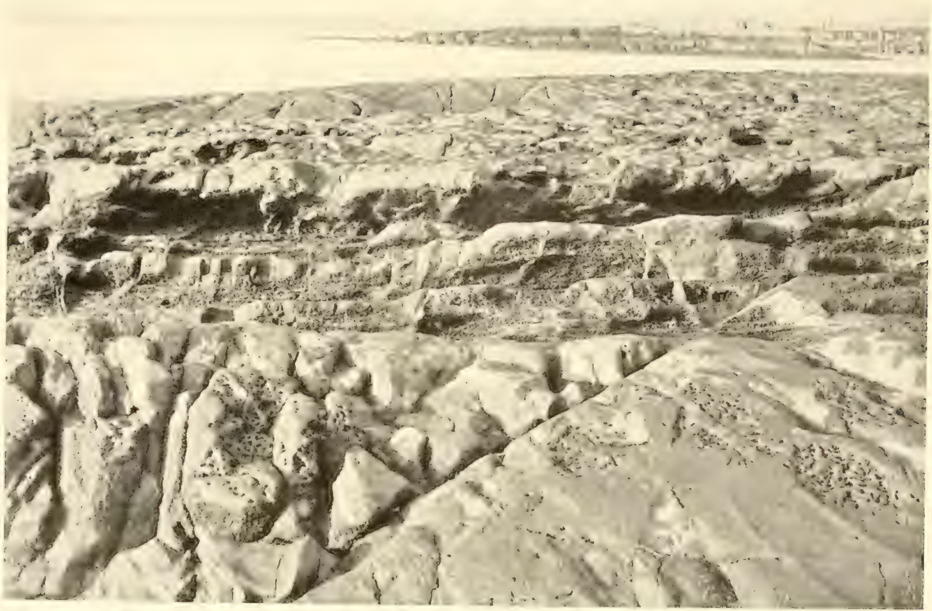


FIG. 42. Another of the pistol crabs (*Crangon* [*Alpheus*] *pachychirus*) stitching together the edges of a furrow in an algal mat to form a tubular retreat. After Cowles

thread from the opposite edge, pulls it back through the first edge. Simple though this stitch is, it holds the mat edges firmly together. Moreover, our tailor is not to be outdone in cleverness by human seamstresses. He does not sew up the tube from end to end at once, but first stitches it together at intervals—bastes it— and then sews up the intervening places. So fast does this small artisan work that ten minutes suffice for him to form a tube four inches long. With one exception each of the tubes that were examined by Professor Cowles contained two individuals, a male and a female; and in each instance the female was without eggs.

Tube building among Crustacea is not confined to the shrimps. In the amphipods we find a number of almost equally surprising performances (Plate 62.) *Cerapus* builds a most serviceable tube, spun from a glandular secretion. Transparent when new, it soon becomes dark and opaque as the animal affixes to it by means of a sticky



Ledge of San Pablo sandstone, in San Francisco Bay, showing the erosive action of the isopod borer (*Sphaeroma pentodon*). Courtesy of Albert L. Barrows

PLATE 62

Amphipod tube builders. After Della Valle

secretion tiny fragments of algae, hydroids, and the like, as well as a great many little pellets unidentifiable other than as the excrement of the animal. The tube is apparently never attached to its inhabitant, which, however, carries it about and is little more than an animated jack-in-the-box while under observation. The rapidity with which the amphipod's head appears first at one end of the tube and then at the other, especially when the animal is disturbed, is almost magical. To effect a change of location *Cerapus* apparently pulls himself and his housing along the ground.

A related amphipod, *Cyrtophium*, swims about in his tube, now in an upright position, now obliquely, now sinking to the bottom like an eddying morsel of driftwood. The tube is a bit of hollow grass stalk lined and overlaid with the hardened hyaline spinning-gland secretion. In repairing his dwelling *Cyrtophium* completely withdraws himself into its confines and then slowly but continuously keeps it revolving around himself. Where the tube is fixed, the animal must do the revolving to keep the tube in shape and condition.

Unciola, though tube-dwelling, is a lazy fellow, preempting the tubes of other amphipods or those constructed by worms. Some species of *Siphonectes* use an old *Dentalium* shell, the mouth of which they narrow to suitable proportions with agglutinated fragments of shells and pebbles. The hermit crab uses a shell as his dwelling (Plate 63) without undertaking any particular remodeling of it; but he himself undergoes a series of anatomical modifications, adapting his body to the domicile and his hands to its opening (Fig. 43) so as to form of them a door secure against the attacks of enemies.

The hermit crab will make use of some other protective shelter if a suitable molluscan domicile is not at hand. Some members of the East Indian genus, *Coenobita*, have been seen with the abdomen stuck in the half of a coconut shell, in joints of bamboo, broken lamp chimneys, and

other suitable substitutes. Other crabs than hermits have taken to molluscan protection, too; for example, *Hypoconcha*. His back has become shaped so as to fit snugly into the half of a lamellibranch shell. Such a home has no elasticity and, like that of the hermit, must be ex-

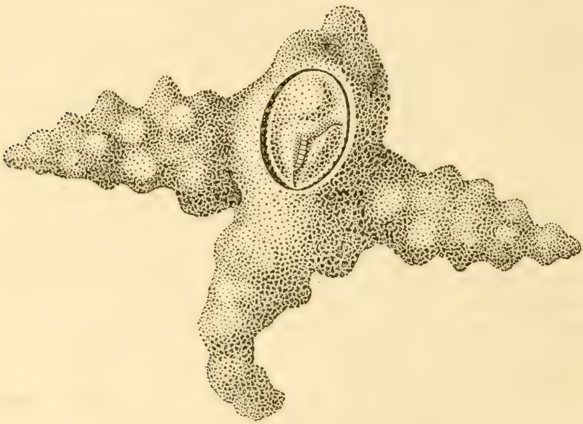


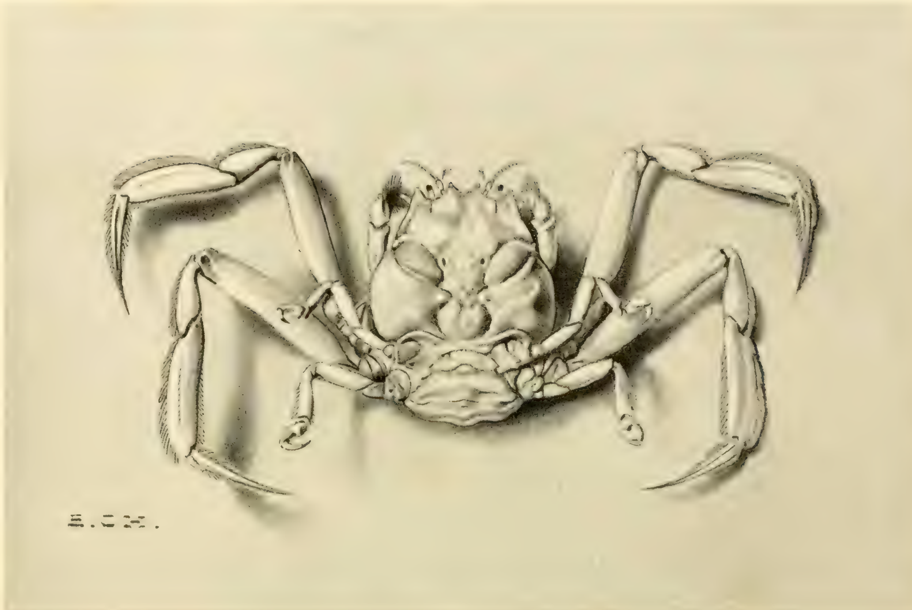
FIG. 43. Hermit crab (*Pagurus corallinus*) sheltered in home formed by an encrusting bryozoan, *Schizopodrella*. The crab's big claw forms a protecting door

changed for a larger one from time to time as the inhabitant increases in size. *Dorippe*, "the crab with the human face" or the "demon-faced" crab (Plate 64), has the same shell-carrying habit. In some parts of the Orient *Dorippe* is held sacred, for the slant-eyed face that is so readily to be traced in the areolations of his carapace is likened to the deceased relative whose soul has passed into the crab.

Like *Hypoconcha*, other dromid crabs have the hinder legs turned up over the back in order to support their shelly housings. The houses of the dromid crabs are indeed most wonderful affairs, increasing in size and in the protection

PLATE 63

Hermit crabs (*Pagurus bernhardus*) at home in shells. After Schensky



Dorippe, called by the Chinese "the crab with the human face" because of the sculpture of its carapace

they afford as the tenant grows. These unique and portable residences are live ascidians or sponges which the dromid acquires in youth and totes about for life, unless he chooses to make a change. So well do these living bits of their environment house the dromids that unless they are on the move they can be spotted only by the closest observer.

Under natural conditions a dromid in need of housing very methodically goes about cutting out the necessary material from a convenient sheet of incrusting sponge, using its chelae as a cutter. As the piece is freed somewhat and as soon as its edge can be raised, the crab gradually works himself under, cutting away till the whole piece is dislodged from the matrix. Within a few days the growth of the sponge and also, no doubt, the trimming given it by the crab cause the rough edges of the cover to disappear and it takes on the regular shape of one that has been long in use for this purpose.

Where a sponge case is not as easily lifted as described above, the crab will trench the original groove more deeply, working after the manner of a man attempting to dislodge an object similarly attached. When the dromid thinks the grooving and undercutting have gone far enough, he climbs above and, grasping the sponge with his claws at two points along the furrow, gives a good heave. If the sponge is too tightly seated, he goes back for another spell of undercutting.

Very often the manufactured case is too flat, and it never fits exactly to the surface of the crab's back. The crab corrects this by pressing the sponge tightly to his back and bending it out. As the tissues of the sponge are fairly plastic, it soon takes on a fairly definite shape, particularly as regards the inner concavity into which the crab's back fits. It has a definite cut and points of orientation of which the crab is fully cognizant, as the removal of his accustomed case will demonstrate. After its removal, if he is permitted to do so, the crab does not long delay in

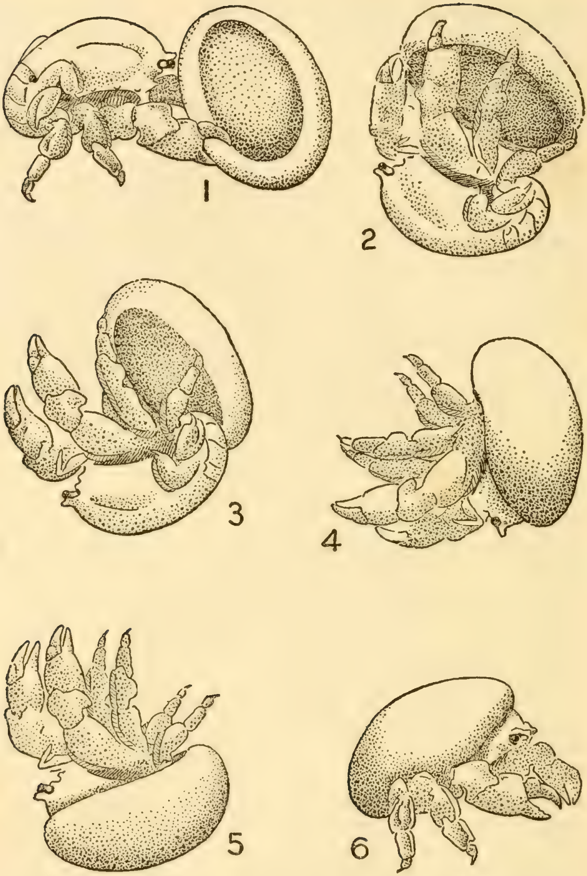


FIG. 44. The manner in which the dromid crab (*Dromia*) puts on his sponge coat. After Dembowska

returning to his house (Fig. 44). Taking hold of it with his chelae, he rolls over on his back, lifting up the case, concave side downwards, at the same time. Now he rotates it with his legs; then, grasping it with the hooks of the fourth and fifth legs, he tilts its hinder margin into the air, at the same time sliding it down over his back as he stands on his head. This brings both case and crab into the proper position relative to each other, but for the moment both on their front ends—a position obviously of unstable equilibrium, which results in the crab falling on his feet in natural position or else on his back and in the case. Then he must needs right himself by any of the normal means known to crabs, with the case held meanwhile close to his back.

If one tries to puzzle the *Dromia* by weighting the upturned case with small stones so that it is too heavy to be picked up by one of the usual modes, it will not be long before the animal has freed the case of the extraneous matter. He always gives the case a preliminary try, and if the object proves too heavy, he presses his fore or hind part between the sponge and the ground until he overthrows the case and causes the stones to fall out.

Deprived of the materials provided him by nature for fashioning his case, the dromid will make use of paper or rags, if either of these is offered him, or may even accept a man-made case of plastic clay. Usually he will quickly discard the paper or rags for a natural cover, but less readily the artificial clay case, especially if he has become accustomed to it for a period of time. In fashioning a paper case the dromid is as clever with his claws as any child cutting out paper shapes with scissors. He usually begins working at one edge, from the underside of the paper, making little tears in it. Though these seem to be more or less irregular, he always works in a definite direction, taking hold, tearing, moving along, and tearing again, until an approximately elliptical piece is cut out. He may work lying on his back beneath the paper or in his

normal position, holding it with his other legs while the claws do the piercing and cutting. Rarely is the future case damaged in the making by a wrong or too great a tear.

Dromia gets so used to his own sponge case that he can usually pick it out from many other sponges. Among a variety of materials *Dromia* "always chooses a sponge." When we try to puzzle this crab still more by hiding his case under pebbles, he will, if the performance has been gone over repeatedly and gradually, learn to look for it, even if completely concealed. If the case is anchored, *Dromia* is ingenious enough to effect its release. Miss W. S. Dembowska's account of experiments conducted to bring out these points had best be told in her own words:

> In another series of experiments I fastened the sponge to a little wire hook. In the meantime the crab manufactured a new case of paper. In order to make the sponge more conspicuous I chose a red one and put it into a porcelain dish, hanging it so high on the wall that the crab could hardly reach it. When I put the crab in, it directed itself at once toward the sponge, dropping the paper case on the way. With some difficulty the animal succeeded in grasping the hanging sponge with the chelae. It then climbed over the sponge, very soon found the wire hook, and began to tear off small pieces of sponge around it. After a short time the sponge became liberated and the *Dromia* rolled down with it, and put the sponge on the back. From the moment of putting the crab into the vessel to the liberation of the sponge, seven minutes elapsed.

Many spider crabs are artists in make-up. Nature has kindly provided these decorator crabs with patches of hooked hairs on the back; and on these the crab impales seaweeds and other marine growths, after first chewing the lower ends to enable them to be more securely hooked to the crooked hairs (Plate 65). Such decorated crabs are verily traveling sea gardens. Sometimes sponges grow in such a garden, building up to most startling heights; and the crab could not transport them were it not for the supporting power of the water.

Spider crab (*Oregonia gracilis*) carrying a camouflage of marine algae, hydroids, and bryozoans

PLATE 66

A crab of the Indian Ocean (*Lybia* [*Melia*] *tessellata*) bearing in its claws two sea anemones for defense against the anticipated attack of a fish. Adapted from Borradaile

A well-masked crab is not only thoroughly concealed from all enemies, but also is most advantageously camouflaged for aggression. Crabs with these masking propensities exercise a fine sense of discrimination as to the fitness of their adornment. They have been subjected to numerous experiments designed to display their surprising faculty of dressing themselves like and with parts or bits of their surroundings. In an aquarium fitted with a choice of strips of colored paper, the crabs will always choose the pieces presenting or most nearly presenting the color of their surroundings. A long series of experiments seems to have proved indubitably that these crabs can probably distinguish all colors and make advantageous use of their perceptions.

Monkeys in captivity have been known to use a stick to get something just out of reach, and some of the apes have employed a club. Peckham has made us familiar with the fact that certain wasps use a bit of rock in pounding down the mud plug of their tunnels; but it is less well known that Crustacea, too, among the lower animals, make use of tools or weapons which they take up and employ with intent and purpose. There are at least two such crustaceans—both crabs—which consciously travel about with accouterments of which they make use on occasion. To be sure, the tools or weapons are living anemones, but they are intentionally and purposefully carried. *Lybia* [*Melia*] *tesselata* (Plate 66), specifically named because of the beautiful tiled appearance of his back, is most unhappy without at least one anemone in his claws—what species of anemone seems not to matter. Sea anemones are richly provided with nettle cells capable of inflicting severe pain; but the claws of *Lybia* are specially arranged for grasping the fleshy bodies of his involuntary weapons, and for holding them so as to prevent them from affixing themselves to him by the basal disc. For want of a whole anemone, *Lybia* will even accept a

fragment; but he discards it for a complete specimen at the first opportunity.

Well may we exclaim, "What order of intelligence is this that can direct the being to which it pertains to take up an anemone and make use of its protective powers; even to distinguish between a useful one and a useless portion of one; to twist and turn the anemone about in the claws until satisfactorily fixed, shift its own position as necessary, and when danger threatens from any quarter, turn the hand batteries of nettle cells in that direction?" Moreover, though at first warning the crab assumes the defensive, with his weapons in hand, he does not foolishly trust everything to them, but sensibly seeks flight if the danger threatens to become overwhelming.

Secondarily, the anemones (the crab always carries two if he can get them) are useful in providing food for their master, because food material that once comes in contact with their tentacles or sticky bodies adheres closely. When this happens to the *Lybia*-borne anemone, the crab with his second legs helps himself to what may tempt his palate, even to the extent of delving within the anemone to withdraw from its digestive cavity what it may have too hastily swallowed. The crab in turn takes care to keep the anemones always neat and clean and free of any extraneous material that may adhere to them.

The other crab that similarly employs anemones as instruments is *Polydectus cupulifer*. *Polydectus* is a most sluggish individual, more prone to hide away and play possum than to offer fight with his weapons, though at times he raises them for purposes of defense. He is supposed to use them more for the prehension of food, and no doubt in a highly interesting manner, but we know too little about him.

CHAPTER VIII

CRUSTACEANS AS FOOD AND MEDICINE

It was recorded during early colonial days in New England that "the least boy in the [Salem] plantation may catch and eat what he will" of lobsters. Let us hope that this early representative of impecunious youth, described so aptly as the "least boy," realized his good fortune and made the most of it. For it is long since unlimited supplies of lobster have been accessible to any of us, let alone the least of us. It seems hardly credible that there was a time when the mackerel fishermen, whose lines the lobsters robbed of bait, regarded them as pests. And not only were they plentiful: they were large. Twenty-five pounders were not uncommon.

The heyday of the United States lobster fishery came to an end in the nineties of the last century. In 1892 the fishery yielded almost 24,000,000 pounds valued at $1,062,392. Thirteen years later the annual yield had fallen to half its former weight, but with a value of $1,364,721. Overfishing has done the trick, and lobsters have become a luxury.

A lobsterlike species, but one which lacks the claws of the true lobster, is the basis of an extensive fishery on the island of Juan Fernandez—reputed home of Robinson Crusoe—off the coast of Chile; the 287 souls resident on the island are almost wholly dependent on this fishery.

The blue-crab fishery of the Chesapeake Bay region yields a catch of about thirty million pounds a year and supplies the market with both the familiar hard-shelled crab and the much relished soft-shelled one, for the latter

form is nothing more than the blue crab in a state of molt. Like the once apparently inexhaustible lobster population, the Bay crab stock is facing marked depletion; and in places where the casual seashore visitor formerly caught himself a sack of crabs for home consumption without much effort, not a crab is to be seen today. Formerly hunted only in summer, the blue crab is now sought also in winter, which it spends in Virginia waters. At this season it is sluggish, does not readily take to the bait, and lies in fairly soft mud. But taking a page out of the oysterman's book, the Virginia crabbers have adapted the oyster dredge to their needs, and the poor crabs are dragged from their winter retreat as well as baited on the fisherman's line most of the summer. Each year the supply grows less, the price higher, and the chase more intensive. Such seems the trend in all highly exploited crustacean fisheries.

A certain stone crab, *Menippe mercenaria* (Plate 69, upper), is much sought after in Florida—so much so that stringent protective measures have had to be enacted to prevent its possible extinction. But there is hope for the species if those who dine on stone crab will confine themselves strictly to the claw. In fact, the big claw is the portion of the crab most commonly served; and, large and heavy as it is, it contains such a delicious morsel of flesh that one can afford to discard the remainder of the body without regret. The crab may then be left, minus his big claw, to reproduce his kind, and, incidentally, to grow another big claw.

In Sarasota Bay, Florida, the fisherman seem to make a regular practice of breaking off the large claws of their catch and throwing the crabs back, a procedure which seems strange to one not acquainted with that marvelous faculty of regrowing lost appendages with which crustaceans are endowed.

Andalusian fisher folk, also, follow this practice, and have done so since antiquity. In the region about Cadiz

the fiddler crab is so treated. On market days in Seville women peddle the claws of male fiddlers, carrying huge baskets of them about the streets.

Thus the crab is permitted to live in order to provide the market with another claw the next year—for it takes a year to grow a second big claw. And, surprisingly enough, the claw that begins to grow, molt by molt, after the injury, to replace the one that was involuntarily sacrified as food for man, is the opposite and smaller claw; and it continues to grow until it approximates in size and appearance the original big claw. At the same time the newly formed claw, appearing where the big one was removed, becomes a new small claw. With each removal of the succeeding large claw, this curious phenomenon of the reversal in size of the chelae takes place.

Crustaceans themselves seem aware of the fact that their limbs may be broken off fairly easily; for in fighting with one another the chief endeavor of each of two combatant fiddler crabs seems to be to wrest off the other's larger claw. We have already discussed the physiology of this wise provision of nature in our second chapter.

The Andalusians usually catch crabs by a method almost universally employed to secure burrowing crustaceans; that is, by thrusting a pointed stick in the ground beneath the animal to cut off its retreat when it is observed in the upper portion of its dwelling. But sometimes the fishermen simply dig the crabs out with their bare hands.

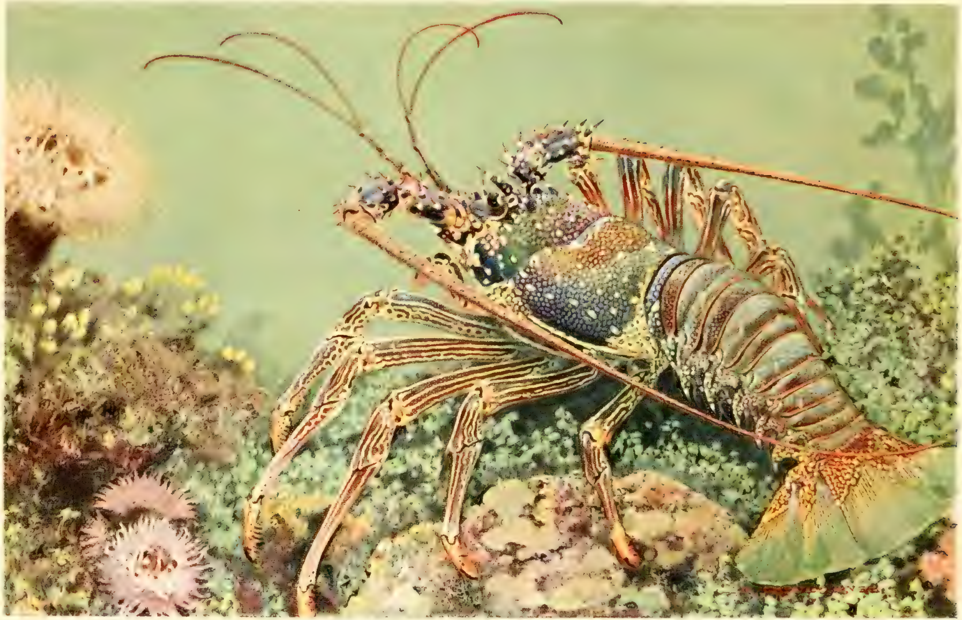
The crabbers of Sarasota Bay, on the other hand, secure their catch by poking a stout iron rod into their holes. Stone crabs are the bulldogs among Crustacea: they lay hold of the rod with such a powerful and tenacious grip that they may be drawn forth from their retreat and secured before they will let go. Thus are the claws taken.

The Chilean natives on the west coast of Patagonia employ a simple device for the catching of the long-legged

lithodid crabs (Plate 69, lower), of which they are very fond. The summer is the season when the crabs are more easily taken, for then they come from the deeper to the shallower water to breed. The fishermen take pains to catch first a female crab, which they do with a line and bait. Having got her, they attach her firmly in a noose and lower her back into the water. The male crabs are ardent wooers, and five or six will so firmly embrace the tethered female on each immersion that they can be drawn to the surface, picked off, and the love lure used again and again. There is a native saying, "A female crab is worth a dozen males." I am told that the same procedure is followed by the Italian fishermen in catching the squid (cuttlefish) in the Mediterranean.

The spiny-lobster fishery of Ecuador is carried on by a few natives in as primitive a manner as is any fishery I have ever witnessed anywhere. In an archaic and not too substantial craft the fisherman paddles about the rocks where the lobsters have been found to resort. He leans over the side of his canoe as it drifts, and when he notes the telltale long feelers gently working to and fro from beneath some sheltering rock or niche, he takes a good deep breath and dives overboard for his catch. And remarkably successful he is, too, each time. I was amazed at the performance. How could the fellow see through the rush and swirl of water as the sea rose and fell among the projecting rocks? He neither heard nor knew of such a thing as a glass-bottomed bucket or box, such as is used by our Florida spiny-lobster men; yet in two or three fathoms of water he was as successful, at least over a short period of time, as they are with spear or tickler and net.

Another crustacean which is highly regarded as an article of table fare is the shrimp, and shrimp fisheries exist in many different parts of the world. The most productive ones in the United States are to be found along the Atlantic coast of Florida and in the Gulf of Mexico.



A common spiny lobster of the Indo-Pacific region. The species here represented is *Panulirus penicillatus*, which attains a length of sixteen inches. This is the same species that is figured on the walls of the temple at Deir-el-Bahari, about 1500 B.C. (See Plate 34). By E. Cheverlange

The demand for this food along our south Atlantic coast is almost beyond conception. At New Orleans more than two thousand people are employed in catching and canning shrimp. In central and northern California, also—where shrimps are relished even more than are peanuts by baseball fans—the industry has reached large proportions. In San Francisco Bay, however, the supply was perhaps larger in bygone days than it is now. The fondness of the Chinese residents for this delicacy led to their establishing extensive fishing camps, which produced a surplus, over the local demand, of ten million pounds a year, the bulk of which was dried or salted, or both, and exported to China. But the industry was so intensively pursued and the nets employed were so fine of mesh that an almost wholesale destruction of marine life resulted. Thereupon drastic laws were invoked, which summarily put an end to the fishery. For some time, now, shrimp fishing has been restricted to those parts of the bay least frequented by the fish fry, in consequence of which the industry seems to have almost wholly recovered.

The delicate, transparent fairy shrimps form the basis of a very considerable but comparatively unknown fishery in the English Channel, and no doubt the industry has there been prosecuted in much the same manner and for the same purpose ever since the Norman Conquest—perhaps before. The island of Jersey is the scene of this fishery; and here the mysids are compounded into a paste called *chervé*, which is sold to mullet anglers for bait.

In the Orient, species of mysids closely related to the Jersey shrimp are used as human food, and the shrimp fisheries in the Gulf of Siam are probably the greatest in the world.

In Brazil shrimps are peddled on the street, weighed out on a primitive sort of wooden beam that reminds one of the days of Daniel Boone. As quaint is the custom in our own Charleston (South Carolina), where these

decapods are peddled from door to door, measured out for sale by the tin plate full.

Crayfish, also, must be classed as edible crustaceans, for they are consumed abroad in prodigious numbers. As long ago as the time of the Roman empire they were held in high esteem, although as a rule they were the food of the poorer classes. The slaves ate the crayfish just as they were caught, that is, without giving them any preliminary care; but those destined for the tables of the elect, including the royal table, were first fattened in earthenware pots designed for the purpose.

And man is not the only animal to which crayfish are acceptable as food. Snakes, salamanders, raccoons, otters, alligators, and certain birds relish their flesh. Audubon, the great naturalist, has left an interesting account—worthy of repetition here—illustrating the intelligence of the white ibis in catching the burrowing crayfish, *Cambarus diogenes*. With circumspection, this authority says, the bird approaches the mud chimney of his intended repast and so breaks up the painstakingly constructed cylinder of clay that some of the débris falls within to notify the dweller that repairs are in order above. With a foreknowledge of what will take place, the bird withdraws a little and awaits the outcome. The poor, diligent crayfish, as soon as everything seems quiet above, begins to clean the extraneous mud and matter from within and to carry it to the surface to restore his broken chimney. There, of course, he meets his fate, and once again the ibis has stilled the pangs of hunger.

Man nowhere makes a practice of eating the minute crustaceans—such as copepods—which abound in the seas and make up so much of the bill of fare of many fish and other aquatic animals. But on one occasion at least tiny amphipods were all that stood between twenty-five men and death. These twenty-five men made up the Greely Expedition to the Arctic, which ended so tragically half a century ago.

With supplies for only a year or two at the most, the expedition passed three years in the Arctic and lost eighteen members of its original personnel of twenty-five. The seven rescued owed their lives to the amphipods, as a few extracts from the log of the expedition will show. The first man died on January 18, 1884. We have pieced out the subsequent story from General Greely's account, which we give herewith, largely in his own words:

March 5. The last of our seal blubber, corn, tomatoes, potatoes, and soup issued today—what shall we do in a few days?

March 16. Brainard made an improvement on my plan of last autumn to dredge for mussels, and suggests that we try and catch shrimps. Certainly our men are full of devices, and we shall yet make a brave fight for our lives.

March 21. A net was made in which to catch shrimps; an improvement of Rice's plan of yesterday.

General Brainard himself described these nets for me. They were improvised from iron barrel hoops and pieces of sacking and were first baited with such bones and meat scraps as could be spared. Later, as the stringency became greater and greater, little puckers of sealskin, sometimes sewed over stones and fastened into the crude net with the inner side up, served as bait. The whole idea was born of Brainard's observing that countless numbers of amphipods completely devoured every scrap of offal that was thrown in the water. So numerous, active, and all-consuming are these little crustaceans that naturalists visiting the colder regions, where they occur in the greatest abundance, make use of their insatiable appetites to skeletonize such animals as they wish to save for osteological study.

March 23. Rice, indefatigable as ever, was out at 3 a.m. for shrimps. Unfortunately he overturned his net, and brought in only a few ounces.

March 25. The shrimps are now mixed with our stews,

and are quite palatable. The minute animals have opened up to us a new avenue of escape.

March 27. Rice made four trips, and succeeded in getting twelve pounds of shrimps.

March 28. Rice was very successful, and got twenty-seven pounds of shrimps.

April 5. Christiansen died.

April 6. Lynn died.

April 9. Rice died.

April 9. Lockwood died.

April 12. Jewell died.

Brainard was very successful in bringing in twenty or thirty pounds of shrimps daily, thus enabling us, with a few ounces of meat, to keep body and soul together.

April 29. Jens was accidentally drowned while out trying to get a seal.

May 18. Very stormy last night and this morning. I heard a raven croaking this morning and called Long, who succeeded in killing him. Gave Long the liver, and concluded to use the bird for shrimp bait, thinking we could obtain more from him that way than in eating.

May 19. Ellis died, the first death from starvation in six weeks.

May 22. It is now eight days since our last regular food was issued.

May 23. Ralston died. Brainard got only ten pounds of shrimps, less by far than we are eating. It is a sad state of affairs, and the end must be near.

May 24. Whisler died. For dinner we had a handful of saxifrage, two or three spoonsful of shrimp, and a pint and a half of tea. The cook was caught unfairly dividing our wretched shrimps, giving equal soup but keeping too great a portion of shrimps, and I ordered him relieved as cook. Of the party, at present seven are helpless.

May 26. The storm was so bad this morning that Brainard could not go shrimping, but this afternoon he got eight pounds. Owing to his failure to get shrimps we

PLATE 68

An aged European edible lobster (*Homarus gammarus*) much overgrown with barnacles. After Schensky

Two edible crabs

Upper: Stone crab of Florida (*Menippe mercenaria*). Note the stridulating ridges on inner surface of the claw. After Mary J. Rathbun. Lower: Lithodid crab (*Lithodes antarctica*)

had a stew last night and this morning of deer thongs, which have been used in lashing together the sledge and for similar purposes.

May 27. Israel died.

June 1. Kislingbury died.

June 3. Salor died.

June 4. Henry, the cook, stealing shrimps again.

June 5. Brainard got only five pounds of shrimps.

June 6. More shrimp stealing. Henry, the culprit, shot.

June 6. Bender died.
Dr. Pavy died.

June 7. All the shrimps left were eaten for breakfast.

June 12. Gardiner died.

June 14. Today three years since the expedition sailed from Baltimore.

June 15. Brainard gets few shrimps.

Schneider writes in his diary, "The sleeping bag cover roasted and boiled to suit each one. I had my skin boiled."

The journal ends June 21.

June 23, all but dead, the seven miserable survivors were rescued by Commander Schley, later the Admiral of Spanish War fame, in command of the *Thetis*. Seven left of twenty-five, and those seven owed their lives to "shrimps," the tiny little amphipods so plentiful in northern waters. General Brainard has told me that they got, all told, perhaps fifteen hundred pounds of them.

Other crustaceans likewise, less well known than lobsters, crabs, and true shrimps, may be classed as human food, since they are used for this purpose in many parts of the world. Such are the vicious mantis shrimps, or split-thumbs, and the barnacles. I have already spoken of the large consumption of barnacles in Chile; and I am told that they are in equal favor with the aborigines of our northwest coast, where several large species occur. Thus it will be seen that no summing up of the sources of human

food is complete which does not include Crustacea; and from my own observation I should say that all members of the class should be included, as I know of no crustacean in the fresh, unspoiled state that is poisonous or otherwise unfit for human consumption after cooking.

What is more, it appears that crustaceans are a health-giving food. Recent medical findings reveal that iodine in an organic combination yields better results than iodine in the form of inorganic salts. Now all sea foods, including marine crustaceans, contain iodine, glycogen, and the like in this desirable form. And so crustaceans assume a new value for man: they are a source of medicine as well as of food.

So much for the therapeutic value of the crab, the shrimp, and the lobster as revealed by modern biomedical research. The medicinal value of Crustacea, however, though long believed in, has not always been grounded in science; nor is it yet, everywhere in the world. Geologists working in China, for instance, have learned to their disappointment that fossil crabs are rare finds, and this largely because of the high estimate placed on their medicinal properties by the natives. Innumerable virtues are credited to these petrified crabs. They are considered an excellent antidote for neutralizing all kinds of mineral, metallic, and vegetable poisons. They are also highly regarded as a vermifuge, a most necessary remedy in a country so overrun with human parasites as is China. These fossil crabs are also believed efficacious in curing opacity and other affections of the eye.

But if we scoff at the Chinese for putting useless drugs in their pharmacopeias, we must, on the other hand, give them due credit for an ancient practice which is in accord with our most recent findings—the treatment of goiter with iodine. According to native writers seaweed, with its valuable iodine content, has long been used by the Chinese as a remedy for goiter.

From Pliny we gather that the ancients had several

European edible shrimp (*Pandalus annulicornis*). After Schensky

strange uses for river crabs. Freshly macerated and swallowed with water or in the form of the ash of the burned crab they were considered an antidote for all poisons, especially when taken in ass's milk.

Even our own ancestors of no very distant generation prescribed live crustaceans in certain maladies. And they were not crabs or shrimps, either, but the little isopods called sow-bugs or pill-bugs, which are found in damp cellars or under boards in the back yard. The pill-bug acquired its common name from its resemblance, when curled up, to a pill and from its use in former times as a pill.

In western Europe a few centuries ago every human ill, from heart affection to cancer and from club feet to scrofula, was supposed to yield to the magic of crayfish "eyes." The crayfish or crab eyes are little natural concretions, rounded discoidal nodules of whitish limy matter, laid down in concentric rings on each side of the animal's stomach. The primary purpose for the secretion of these nodules seems to be to furnish the newly molted animal with a readily available store of calcareous material with which quickly to make its new shell as hard and stiff as the outgrown one. To the uninitiated these eyes or stones are considered charms or luck stones. Even in this day and time we receive them at the Museum for determination, and as often as we receive them we are interrogated as to their medicinal property.

In Jamaica there exists a local superstition that the fiddler crab can cure deafness and earache, and it is called, therefore, the "deaf-ear" crab. The treatment consists in crushing the live crab and pouring the juice thus obtained into the afflicted ear.

In Korea the raw juice pressed from the river crayfish is used therapeutically in cases of fever and diarrhea. The results, however, are lamentable and frequently fatal. The Koreans eat quantities of fresh-water crabs—*Eriocheir sinensis*, *Potamon dehaanii* and *obtusipes*, and *Sesarma dehaani*—in their raw state; although these crabs, as well

as the native crayfish, are intermediate hosts of the extremely prevalent lung fluke found almost everywhere in the Orient. In some districts from eighty-four to a hundred per cent of the crabs are infected; and, naturally, unless they are thoroughly cooked, they will pass on the parasite to whomsoever eats of them. Thus more than fifty per cent of the population in Korea is infected; and in Japan, too, the rate is high. Dogs, cats, and other carnivorous animals, as well as man, become infected; and in countries where the lung fluke is prevalent it is a greater scourge than the hookworm. Not only does it invade the lungs, producing a chronic cough, blood spitting, and an anemic condition, but it penetrates the brain as well, giving rise to all manner of curious afflictions that have been variously diagnosed as infantile paralysis, cerebral hemorrhage, encephalitis, and the like. I can not stress too strongly the danger of eating these crabs of the Orient when not thoroughly cooked, or that of eating, in infected districts, any uncooked food which has been washed in water or drinking unboiled water.

Even the tiny Entomostraca loom large in medical annals as intermediate hosts of a number of unpleasant parasites. Napoleon's soldiers in Egypt were troubled by a pernicious "guinea worm," which they got from drinking water carrying its intermediate host—the fresh-water copepod *Cyclops*, which is found in India, Arabia, and Africa.

And our own Great Lakes region has been invaded by a human parasite new to the western world—the fish tape of Europe (*Diphyllobothrium*). Like the guinea worm, it makes use of the fresh-water *Cyclops* as an intermediate host, spending part of its life in this crustacean, another part (the second larval stage) in fish, and the balance in whatever vertebrate offers—be it man, feline, canine, or water bird. The danger to man in regions where this tapeworm occurs lies only in eating infected fish without first thoroughly cooking them.

CHAPTER IX

THE SINS OF CRUSTACEANS

It may seem rather cavalier treatment of the Crustacea to save the account of their sins—from the human point of view—to the last. By so doing we appear perhaps to convict our friendship of hypocrisy, in view of all the praise previously heaped upon them. But the tale will probably not rob the epicure of his taste for soft-shelled crabs, nor the student of his newly aroused admiration for the class as a whole. And the sins of Crustacea, like the sins of some great men, make up the most interesting part of their biographies.

The earliest recorded account—as far as I know—dealing with the economic conflict of crabs and men was written in China in the sixth century B.C. A wise counselor of the then king of Yueh (now the province of Chekiang) warned his master that he should abandon his warlike preparations because of the ravages of the rice crab, "that spared for man not a seed [of rice] in late years."

In India there are nearly a dozen different species of crabs causing appreciable damage to rice and the fields where it is grown. Some attack the tender young shoots; others seem to fell the standing grain, or else—in fields located on the sea coasts—so to weaken, by their burrowing, the dikes that impound the water necessary to the plants that salt water is let in. What is worse, and also more common, the burrows of the crabs drain the fields and expose the tender grain to the devastating heat of the tropical sun. In Ceylon, where rice is grown on ter-

races along the hillsides, the crabs weaken the bunds, or dikes; and the continued rains of the long wet season complete their destruction. The breaks not only allow the water to escape and the rich soil to be washed away, but they are also the cause of the young plants in the paddy below becoming overwhelmed with silt and dirt.

Poisoning has been tried to combat crab pests in rice fields; but the poison is apt to become too dilute, in the presence of so much water, to have much effect. Trapping the fellows in rotund, wide-mouthed jars has proved successful in Ceylon. The pots, baited with boiled rice bran, are buried three or four inches below the level of the water, where they are readily sought out by the crabs; and once in the globe-shaped pots, they can't climb out. Once in Mandalay, in rice fields covering sixteen acres, twenty thousand crabs were so potted during the two months of the year when the young sprouts are most subject to damage. The natives have discovered that the crabs are more active during or just after a rain than at other times and that they can rouse them from their burrows by beating on the ground with a switch to simulate the fall of rain. When the fields are drained for harvesting, and in the dry season particularly, the crabs tend to hibernate: in the course of well digging they have been uncovered at depths of five and six feet, comfortably ensconced in pockets of moist mud.

Udang ketak, as the natives call him, is the miscreant that damages the bunds of the rice fields in the Federated Malay States. He is the shrimplike *Thalassina anomala*. Very numerous in the mud of tidal areas, shrimps of this species dig large, ramifying burrows many yards in length and extending downward at least to low-tide level. In the excavation of these subways, the earth which is passed out takes on the shape of mounds, which reach the astonishing height of two feet or more. So numerous are they that in some places walking is impeded, each large hillock being so close to its neighbor that it is difficult

to find a footing among them. Along muddy coasts, where the *Thalassina* are at home, these mounds are a conspicuous feature of the landscape. In the rice-growing sections of their range, the shrimps tunnel the bunds in all directions, letting in the salt water at high tide and, like the crabs again, letting out the fresh water. Lime placed in the burrows has been a successful deterrent, but too much of it is harmful to the rice lands.

The province of Valencia, in Spain, is best known, perhaps, for its oranges, lace, bull fights, and beautiful women; but it is a great rice-growing district as well, which is why our attention is attracted to it in considering Crustacea as pests. For there lives the entomostracan *Apus*, which makes depredations on the rice plants. *Apus* is a little fellow a couple of inches long which looks like a baby horseshoe crab. In Spanish the name is *tortugueta* (little turtle). Occurring at times in enormous numbers, the "little turtles" stir up the fine silt in which the rice is planted, expose the roots, and kill so many young plants that they become a serious menace to the rice stand. Draining and partially drying the fields would kill or carry them off; but then an even greater evil would result, inasmuch as great flocks of birds are waiting for just such an opportunity to get at the rice. It is better to poison these crustacean pests, especially as *Apus* succumbs to quite dilute solutions of such poisons as chloride of lime, sodium cyanide, or ammonium chloride.

The successful growing of rice in our own insular possession of Porto Rico is also jeopardized by crustacean pests. Here the Department of Agriculture is trying to combat the large gray land crabs, *Cardisoma*, which can wipe out whole fields of the grain at one fell swoop. The fields where rice can be grown are formed by raising low dikes on ground which fortunately is underlaid by a clayey stratum, impervious to water. But the "pesky" crabs, which burrow by nature, seem to find the rice fields ideal places for opening new subdivisions; and once they

penetrate the water-retaining layer of clay, the water goes through it as readily as it would through a gigantic sieve or colander. These same fellows are found in southern Florida (Plate 71), where they are inordinately fond of the sprouting tomato plants and nip them off as soon as they poke their way above the surface of the ground. The number of crabs infesting these tomato lands runs from five to ten thousand to an acre. To eliminate them costs from fifteen to forty dollars an acre, the lower figure applying to previously untilled ground. They present no simple problem, especially when they can scale a thirty-inch cement retaining wall with apparently little difficulty. But then, again, these are no little fellows, for one has been seen in Dade County, Florida, with a maximum spread of twenty-two inches.

Crustacea are also among the list of animals that prey on the much harassed cotton plant, particularly in the Mississippi delta region. Here it is the crawfish that cuts down the sprouting plants; and, like the land crab, he, too, must be laid low with poison in his burrow, carbon bisulphide being chiefly employed for this purpose. As we examine the Yearbook of the United States Department of Agriculture for 1911, we can but be astounded by the destruction wrought by these crustaceans. We read, "Over a wide stretch of country, estimated at not less than 1,000 square miles, crawfish prevent to a very considerable extent the successful production of cotton and corn. They do the greatest amount of damage just after the plant appears and before the secondary leaves are developed. Large fields of young cotton have been destroyed in a single night. Corn also is extensively eaten, but is not so badly damaged as cotton."

Wherever land crabs abound, there man's agricultural enterprises are apt to suffer. And yet the crabs may help as well as hinder the farmer in his endeavors, because they are natural tillers of the land. They are veritable ten-footed earthworms with an enormous capacity for work;

Crab infestations in Florida

Upper: Male land crab (*Cardisoma*), and typical burrows. Lower: Coconut grove heavily infested. Crab traps in background. Courtesy of the Bureau of Biological Survey

and they turn over the soil more thoroughly than man could possibly do, even with all the machines he has devised to aid him. Also the crabs are efficient scavengers of animal and plant refuse, and as they work in great armies they clear away immense quantities of objectionable waste in a remarkably short time. This service is particularly valuable in the tropics, where it is essential to man's health that decaying matter be quickly disposed of.

An epidemic of terrestrial isopods which occurred in Holland is possibly the most striking one the world has known. A colorless or whitish continental species, *Haplophthalmus danicus*, was at one time reported in such enormous numbers in portulaca gardens that the ground was actually white with them. Various means may be employed to keep down these pests. Poison baits made of potatoes—of which the sow-bugs are inordinately fond—sprinkled with Paris green and London purple have proved most effective.

Another isopod—the pill-bug, or sow-bug—also does much damage. Though feasting chiefly on decaying or fallen trees or other plants, pill-bugs often show a predilection for living plants. In fact, in all temperate parts of the earth, if they occur in numbers, their food seems to embrace the greater part of the vegetable kingdom. A fernery in England was once practically ruined by a little fellow as red as the last word of his name—*Trichoniscus roseus*. The place was so overrun with the pests that it had to be taken down—rock work and all—and rebuilt, and the old, infested soil carted away.

Oyster farming suffers from crustaceans in much the same way that ordinary farming does. A near relative of *udang ketak* of the Federated Malay States exacts a heavy tribute from the Puget Sound oyster growers. The *Callianassa*, however, are exclusively marine in habit. In the State of Washington the oysters are grown in shallow "pans" of water shut in by low retaining walls of

concrete. In order to obtain a constant supply of fresh water as well as to secure for themselves a safe retreat, the *Callianassa* extend their subterranean burrows under these walls, thus allowing the water in the pans to escape and exposing the young oysters to the fatal heat of the sun. Even where the burrows do not undermine the walls and drain off the water, the operations of these doughty excavators are apt to smother with silt all the oyster spat within range. Fine silt will suffocate oysters in their infancy, whereas an older oyster would be but temporarily annoyed until the next tide cleared the atmosphere for him.

In France the crabs *Carcinides* and *Liocarcinus* [*Portunus*] are reputed enemies of oysters, and the French oystermen believe they will bear watching. They have been observed detaching, with their chelae, young oyster spat from the plants or other objects to which they have attached themselves, breaking the shells, and devouring the contents. And as to the depredations of an Australian relative of these crabs—*Scylla serrata*—there can be no doubt. *Scylla serrata*, which may attain an over-all span of two feet, does its chief damage at night. With his powerful claws he crushes the shells of the young oysters to get at the meat. He even attacks full-grown oysters if their growth has been rapid, for the shell is then somewhat weaker or thinner. Crabs of this species are said to make seasonal raids upon the young oysters and may devastate whole beds in a few days' time. Stake fences are employed as a protection against such crab invasions.

In the extensive oyster beds at Matapalo, Peru, another crustacean proves troublesome, this time an isopod. Mangroves are plentiful in this locality, and the trees flourish in soft mud. The oysters, having need of something to which to attach themselves, adhere to the mangroves. But now comes upon the scene the isopod—*Sphaeroma peruvianum*—which has a penchant for boring in wood. He enters the stems and roots of the mangroves, causing

the wood to decay. The blighted, honeycombed branches and roots fall away, carrying with them the oysters attached to them, which sink in the soft mud below and are completely blotted out. The native fishermen call this isopod *piojo de mangle* (mangrove louse).

These are not all the crustacean sinners, but they are perhaps the worst, or the best known. Certainly no one will charge that the evil they do outweighs the good, or that crustacean depredations balance the immense contribution of the class to human and animal well-being in general. Our purpose here, however, is not to weigh the Crustacea but to be entertained by them; and if that has been realized, who could ask more—even of a scientist, or a crustacean.

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PART III

MOLLUSKS

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Color effects in the shells of marine gastropods. The beautiful shell of Number 6 (*Oliva porphyria*) is always hidden, in life, by an even more beautiful mantle

CHAPTER I

THE RANKING INVERTEBRATES

EVERY specialist in natural history feels that his own specialty leads all others in interest and even in significance in the scheme of nature. Such partiality constitutes both the weakness and the strength of scientists: weakness because it is an admission of their liability to human error, for certainly they can not all be right; and strength because the belief spurs them to the effort that only the service of the "most important" can call forth. It should occasion no surprise, therefore, if I begin this paper with the claim that the Mollusca rank at the top of all invertebrate life in complexity of organization and intelligence, as they certainly do in size, ferocity, and speed of movement; and that in many of these particulars they surpass groups of the lower Chordata (the animal subkingdom distinguished by the possession of a notochord, or incipient backbone).

So bald a claim probably sticks in the crop even of the layman who makes a mental comparison of the mollusks he knows best—the oyster and the snail—with the colony-forming insects—bees and ants—which have such a high state of social organization and seeming intelligence. On the other hand the claim will probably be accepted, however reluctantly, even by the specialist, who remembers that the octopus and squid, also, are mollusks and compares them with the remainder of the invertebrate world. For it is this upper class of mollusks which hitches the phylum to the top rung of the invertebrate ladder.

At the risk of being technical we can adduce structural evidence to justify our claim. The ten classes of animals

which make up the subkingdom Chordata are held together by only a few common characters, namely, a notochord (the precursor of the spinal column); a neurocoele (the tube in the center of the spinal chord); and a perforated pharynx. Now the perforated pharynx is certainly nothing more than the modified gill of the Mollusca, so that here we have one basic character that ties that subkingdom to the Chordata. A much better claim of the Mollusca to equality with the latter subkingdom, however, is based on the fact that the brain of the octopus (and of all the other members of the class Cephalopoda) is like that of the higher vertebrates including man in one important character: the same complex arrangement of the innervation of the eye occurs in both. This arrangement is called the optic chiasma; in animals possessing it, the optic nerve from the right eye leads not only to the right cerebrum but also to the left; likewise the nerve of the left eye leads to both the left and right cerebrums. It is this high specialization of the brain that carries the cephalopods far beyond even the lower chordates in development.

So much for the right of Mollusca to our respect as "almost equals." The many qualities of all members of the phylum and especially of the Cephalopoda will speak better for themselves than we can speak for them. Among the invertebrates their nearest relatives are the Arthropoda, the subkingdom that includes the crustaceans, insects, spiders, centipedes, and similar forms. Mollusks differ from arthropods in lacking jointed appendages, such as legs and antennae. They are further distinctive in that they go through a veliger larval, or embryonic, stage, a phase of development not found in any animals of lower rank than the subkingdom Mollusca. This will be more fully dealt with in our chapter on the Pelecypoda.

After this brief discussion of relationships we may define a mollusk as a soft-bodied, unsegmented animal enveloped by a mantle, or soft integument, which secretes the protective shell whenever this is present. It is the shell

Cameo cut in a shell of *Cassis cameo*

which springs to the mind's eye at once when the word *mollusk* is mentioned, for there is scarcely a home in the land—or at least there was not in the days of my youth—that did not have an ornamental mollusk shell somewhere about. This was usually a pearly turbo, a trochid, an abalone, a cameo cut from a *Cassis cameo*, or an iridescent card tray made from a single valve of the pearl oyster. The fact that such bric-a-brac has gone out of fashion has not banished the mollusk shell completely from our homes, however, for we still find it functioning in the form of knife handles, umbrella grips, and, more intimately, pearl buttons.

It is the shell also that furnishes us with information about the antiquity of Mollusca; for their fossil shells bear evidence that these animals lived as long ago as the early part of the Paleozoic era—well-nigh the most ancient time from which animal remains of any kind are known; and the shells also bear evidence that these earliest known animals were already so highly specialized as to force us to the conclusion that their ancestors arose far back beyond Paleozoic times.

Perhaps no group of fossils is more used by the geologist and paleontologist to determine the age of geological formations than the shells of mollusks. These shells act as guides in the search for the treasures of the earth's crust, be these water, oil, iron, gold, diamonds or the thousand and one other materials that we extract from the earth.

What, then, is this thing we call a shell? It is the mollusk's skeleton, secreted by the mantle for the animal's protection. An examination of its structure—and this is true whether the shell pertains to an oyster, toothshell, snail, chiton, or even a pearly nautilus—proves it to consist of three layers: an outer thin, skinlike protective layer, called the periostracum; a thicker layer, called the prismatic, composed of elements in the form of little prisms; and an inner, very smooth, shiny layer, called the nacreous, which may or may not be pearly. The periostra-

cum and the prismatic layer are secreted by the edge of the mantle, whereas the nacreous layer is largely secreted by the whole outside of the mantle covering.

This protective casing or exoskeleton (the shell) is of great importance in the classification of mollusks. For classificatory purposes it is comparable in value to the skeleton of the vertebrates. No other single part of the animal's anatomy tells us an equally enlightening story. The shell begins to develop at a very early stage in the mollusk's existence, frequently while the young animal is still in the egg, and certainly while it is still in the brood pouch of the parent. And unlike almost all other typical anatomic characters, this early shell is, as a rule, never shed; nor is it usually modified or overlaid with other structures. But it is added to as the animal develops, and each addition represents a stage in the life history of the species to which the particular mollusk belongs. In the shell, therefore, and permanently engraved upon it, we find a record of all the stages through which the animal has passed from birth to death. I know of no other group of organisms in the whole animal kingdom where a state of affairs so wonderfully helpful to the student obtains. As in recent, so in fossil mollusks—whether of the Pleistocene epoch, which geologically speaking was but yesterday, or of the Paleozoic era, which ran its course endless millions of years ago—the shell records the life history of the species. It is the shell then that gives us the most significant clues to the phylogeny, or racial history, of mollusks and so to their relationships.

Mollusks are found living in the tiptops of some of the tallest tropical trees and at ground level on the earth's land surface or even in the soil, in fresh water, and in the deeps of the sea. This variety of habitat is equalled by the variety of habit of these animals: there are parasitic forms; forms that live as commensals with other animals, that is, forms that live by the efforts of others though not feeding on the body substances of their hosts; forms that

in some stage of their existence, at least, become permanently fixed to a support; forms that roam the high seas; and forms that crawl on the sea bottom or on land.

The adjustment of mollusks to these divers habitats and habits has of necessity entailed many modifications of form away from a generalized type; and the anatomic differences between certain members of the group and similarities between others cause us to recognize four major subdivisions or classes of the Mollusca at the present time. These are:

CLASS	EXAMPLE
Pelecypoda (hatchetfooted)	Oyster
Scaphopoda (plowfooted)	*Dentalium*
Gastropoda (bellyfooted)	Snail
Cephalopoda (headfooted)	Octopus

Of these four classes two are limited to a marine habitat; they are the Scaphopoda and the Cephalopoda. The Pelecypoda—oysters and other bivalves—occur in both fresh and salt water. Only the Gastropoda are found on the land as well as in the sea and in fresh water. In addition to being the most widely distributed, the Gastropoda, which include the snails, are by far the most numerous in species.

As to the number of species of Mollusca, I believe that if we knew all the fossil and recent forms they would total as many as a hundred and fifty thousand. This means that they are one of the largest as they are one of the most diversified of animal groups.

How long do mollusks live? That is a question that can not be answered for all forms. Where known, their duration of life extends from one to thirty years. The oyster is adult at about five years and lives for as long as ten. The garden snail has been known to live five years. The freshwater mussels, *Anodonta*, may live for thirty years.

CHAPTER II

THE BIVALVES

In the bivalves we meet, structurally speaking, the humblest of the mollusks. The clams, oysters, mussels, and their numerous kin have neither head nor jaws nor teeth. Their class name, Pelecypoda, refers to the more or less hatchet-shaped foot common to most, but not all, members of the group. What all the members do have in common is a bivalve shell—the fortress and the skeleton of its possessor—and the animals that live in bivalve shells are built more or less upon a common plan. This applies equally to the tiny *Pisidium*—which may be no larger than a pinhead and which is so prolific that its progeny fairly line the beaches of some of our lakes—and to the huge *Tridacna* (Plate 74) of the western Pacific, whose shell is sometimes used as a baptismal font.

In each valve of a pelecypod's shell may be found either one or two scars marking the places of attachment of the adductor muscles, which close the shell. Muscles which protrude or retract the foot form minor scars. Paralleling the margin is a line of close scars which show where the mantle was attached.

The general structure of the clam or oyster shell is familiar to every one. The two halves are interlocked or hinged together at the dorsal margin by various modifications of teeth, so that they can open and close at the opposite or ventral margin as do the covers of a book. Nature has displayed her customary ingenuity in these interlocking devices and has developed varied forms for the different groups of pelecypods; each form is, however,

constant for each group and so serves as a valuable character for determining relationships. The adductor muscles are those that pull the two valves of the shell together, closing the mollusk in its fortress. (Incidentally, it is the single large adductor muscle of the genus *Pecten* that we eat under the name of scallop.) To open the shell when the adductor muscles are relaxed, the bivalve mollusks

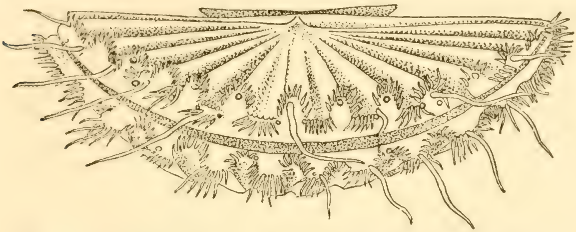


FIG. 45. Scallop (*Pecten jacobaeus*). The edge of the fringed mantle bears many eyes. After Lang

depend on a ligament, which is attached to the two valves at their dorsal margins. This ligament is made up of two layers of fibrous tissue, the outer of which is non-elastic and the inner elastic. It is the inner elastic layer, or resilium, which counteracts the adductor muscles and causes the shell to gape along the ventral margins of the valves when the adductors are relaxed. In some bivalves the elastic material is distributed between the teeth of the valves and thus acts like a piece of rubber—becoming compressed when the muscles close the valves and expanding to force the valves apart when the muscles relax.

We have defined mollusks as animals enveloped in a mantle. The mantle secretes the shell, when there is one, but it has many other important and often quite unexpected functions. The edge of it can generally be seen when the shell is agape, appearing in some groups as a simple flap. In others, however, the edge bears a fringe of long and usually brilliantly colored tentacles, and in the

scallops it is dotted with numerous eyes—as many as one hundred and twenty in a single animal (Fig. 45). Because we are accustomed to looking for eyes in a head, there seems something incongruous in having these organs scattered along the edge of a body covering. But

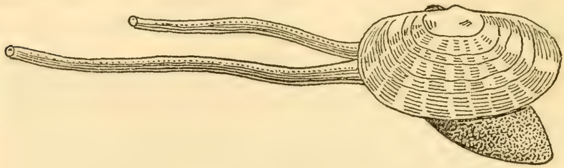


FIG. 46. Paired siphons of *Psammobia florida*. The lower siphon brings water to the gills, the upper one carries it away. After Garner

the pelecypod has no head, and as the edge of its mantle is the part of the body that looks out on the world, it is the logical place for organs of sight. Each of these mantle eyes has a cornea (or lens), a retina, and an optic nerve, so that in some respects it is singularly like the eye of vertebrates. Incidentally, the scallops do not, as a rule, live attached to one spot but are able to swim about by opening and closing the valves of their shells. This habit may help to supply a reason for the development of eyes in these forms.

But to return to the characteristics of the mantle. We find the edge usually modified at the posterior extremity into some form of paired siphons (Fig. 46), whose function is to aid the mollusks in respiration. The lower incurrent siphon brings the water to the gill chamber; the upper excurrent siphon carries it away from the animal after it has passed through the gills. These siphons differ much in size and other particulars in different groups. In some species they are scarcely indicated; in others they are prolonged to many times the length of the rest of the animal, and then they are altogether too long to be tucked

away within the shell when the animal closes that organ. Such extended siphons, however, are exceptional, and in most Pelecypoda the siphons can be safely stowed away within the shell when the animal wishes to seek seclusion within its walls.

The oyster and his kin breathe by means of gills as do fishes, but mollusks use these organs for several other purposes besides respiration. In the bivalves the gills can be seen inside the mantle, looking like four combs suspended from the body. Each of the two gills has two of these combs, called lamellae or hemibranchs, and the teeth of the combs are the gill filaments. Usually the teeth are fused.

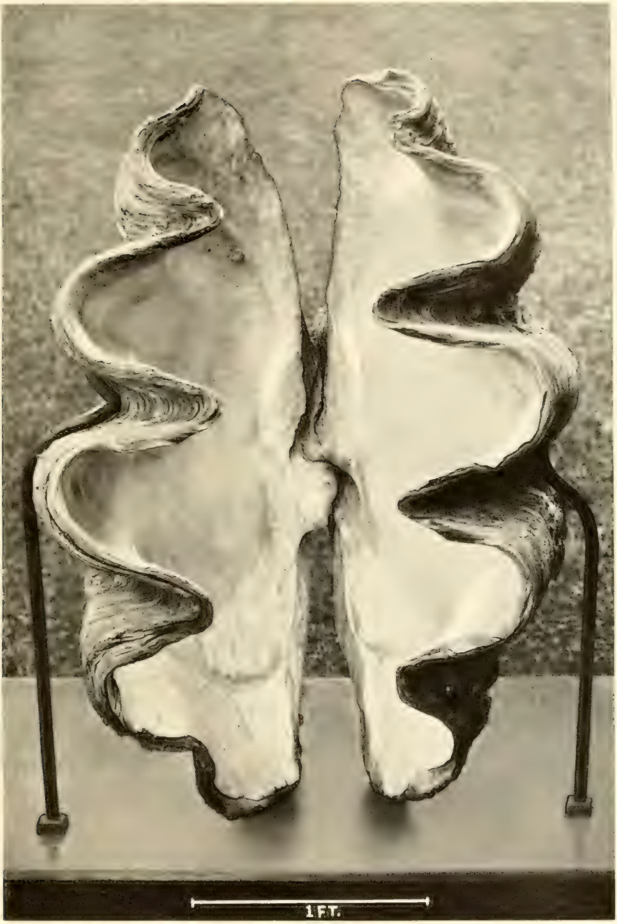
As to the several functions of molluscan gills, the one of prime importance, of course, is respiration. It is through the gills that most of the carbohydrate and fat decomposition products are eliminated from the body, and through them likewise that oxygen is taken up from the water and carried by the blood stream to the various parts of the body. To obtain oxygen the gills must have a constantly fresh stream of water; this is insured by the action of myriads of columnar cells provided with slender, hairlike lashes, called cilia, which flash more or less rhythmically and thus create a current.

A second function of the gills has nothing to do with respiration; it is food getting. The gills are covered with a layer of mucus of their own secretion. When water comes in contact with the cilia, these beat down into the mucus the microscopic life with which the water is laden, while the water is strained through the numerous pores of the gills. Once caught in the mucus, the minute prey is carried along the gill surface by the concerted action of special cilia to the labial palps. "Labial palps" means "lip appendages," and "prolonged lips" might be a very good name for those of the mollusk, for their ciliated covering seizes on the food particles and carries them to the mouth.

As we may well suppose, these various reactions of cilia and palps are automatic—just as the action of man's heart is beyond his control—and will take place so long as water flows over the mollusk's gills. Evidently, therefore, some means must be provided to prevent the mollusk choking with overmuch food and to permit it to discard undesirable catches. This last the mollusk can do at the ventral margins of its gills or through its body cavity.

Many pelecypods put their gills to a third use—that of a brood pouch. Observers of mammals can not but be surprised at such a function until they see what an efficient adaptation it is to the conditions of molluscan existence. The gills are perforated by what are called water tubes, through which flows a constant stream of water; and in these tubes many pelecypod mollusks store their fertilized eggs for further development. The brood pouch thus created is a wonderful device, for it insures the eggs both an ever-changing supply of aerated water and protection, just as do the hatching jars in our fish hatcheries. When the young have reached a definite stage of development, they are passed from the water tubes through the excurrent siphon into the great world beyond to take their chance in the battle of life.

The bivalve's gills are useful organs. And they are hard workers. By a set of very ingenious devices Dr. Paul Galtsoff, of the United States Bureau of Fisheries, has determined that an oyster works its gills for about eighteen hours a day, and that it strains water at a rate of about one gallon an hour, that is, eighteen gallons a day. Some naturalists have stated that in certain reaches of our shore line the waters sometimes contain from 1,000,000 to 2,000,000 organisms to a quart of water; using the conservative estimate of 1,000,000 to a quart or 4,000,000 to a gallon, and multiplying this by 18, we get 72,000,000 organisms that one oyster may take in a day. Multiplying this daily ration by 365 yields 26,280,000,000 organisms as the possible number an oyster may consume



Shell of the largest of the bivalves (*Tridacna gigas*). This specimen weighs 302 pounds

Pinna and glove woven from its byssus

in a year. To carry this a step further, we might remember that in the heyday of the oyster industry, Chesapeake Bay yielded 17,000,000 bushels a year. Since an oyster of goodly size occupies about 8 cubic inches (making 268 individuals to the bushel) the catch for one year alone might have consumed 268 times 26,280,000,000 or 7,043,040,000,000 organisms during its last year of existence. All of which shows the importance of the minute life of the sea.

Since Pelecypoda means "hatchetfooted," we have a right to expect every bearer of that name to possess a foot. Every species of Pelecypoda does have a foot at some time in its existence, and most species retain the foot through life, but some sedentary mollusks, such as the oyster, have no use for such an organ and so have none in adult life. The bivalve foot is laterally compressed, and as it is usually sharp and points downward and outward, the comparison with a hatchet is inevitable. However, it may on occasion be decidedly tongue shaped and much elongated. Naturally the form is modified from the norm to fit the foot for various specific uses, such as to aid its owner in creeping, or burrowing in mud, or digging in sand, or even drilling such hard materials as granite.

The powers of the foot are considerably augmented in certain pelecypods by the presence of a gland, which secretes the byssus. This is a bundle of tough threads of varying length and thickness, which usually resembles a tuft of hair. Certain bivalves, notably any of the black mussels, genus *Mytilus* (Fig. 47) attach themselves to some solid submerged object by means of these threads. Many species that have the capacity thus to anchor themselves seem able to break the attachment and reestablish it at will. But they can hold on with extraordinary tenacity if they choose to do so, as one may assure oneself by attempting to detach a mollusk so secured. Some species make use of the byssus as a climbing mechanism, ascending even the smooth glass side of an aquarium by its aid.

The Mediterranean peoples sometimes gather the byssus threads from the *Pinna* (Plate 75) and knit them into mittens. The fabric thus produced has a silky luster and a golden olive color.

The digestive system of an oyster and his kin, since it fulfills the same function as that of a vertebrate animal

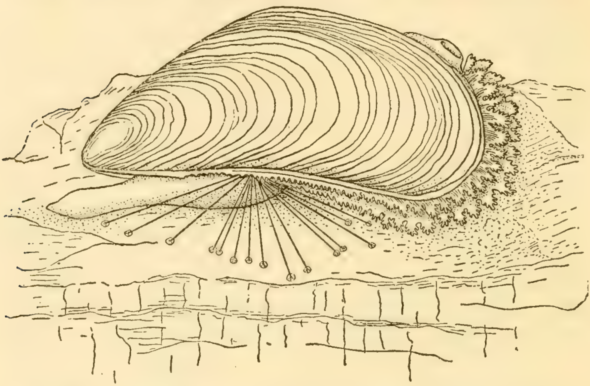


FIG. 47. *Mytilus edulis* attached by its byssus to a piece of wood. After Möbius

and in a comparable way, may be described in the same terms. Thus the food which the labial palps transfer to the mouth passes through an esophagus to an expanded pouch, or stomach. But there is nothing faintly resembling jaws or any other masticatory apparatus. After the food has been acted on by the digestive juices in the stomach, the residue passes into an intestine, from which it is discharged from the animal's body through the excurrent siphon. Recent studies by Younge have shown that the organ in pelecypods we have been calling liver is in reality a diverticulum, or pocket, of the digestive tract, into whose pouches fine food material is carried by cilia

and there digested. The white corpuscles of the blood are also credited by the same author with aiding digestion by leaving the blood vessels, ingesting food particles on the surface of the gill or intestine, and returning to the vessels.

To speak of the blood of an oyster may occasion surprise to those who are accustomed to think of this vital fluid as a red substance. The blood of bivalves is colorless, but they have a well-developed system for its circulation. The pumping mechanism—the heart—has two auricles (or chambers) for the reception of the blood from the veins after it has been charged with oxygen at the gills, and one ventricle (or chamber), for the discharge of the blood into the arteries. The arteries carry the aerated blood to all parts of the body. Once the blood has given up its oxygen to the body cells and become charged with carbon dioxide, it is collected from a system of uninclosed passages, called lacunae, into a venous sinus, whence it passes through the kidneys. Thence branchial veins carry it to the gills for aeration and others return it to the heart. Some of the blood, however, passes directly out of the venous sinus into the branchial artery, and part also passes directly into the pericardium. This causes the mixing of some of the venous blood with the arterial blood coming from the gills to the heart.

The pelecypod has no brain; its nervous system consists of three pairs of ganglia (nerve centers), each usually occupying widely separated parts of the anatomy. These ganglia furnish the nerves to the various organs of the bivalve.

In so sedentary an animal as an oyster or a mussel we should not expect to find highly developed sense organs. There are two patches of specialized cells in the mantle from which nerves lead to the visceral ganglia, and these cells are called the olfactory organs. This does not mean that bivalves have a sense of smell comparable to that of mammals: probably the function of these organs is to

test the purity of the water entering by the respiratory current.

In the tentacles, siphons, mantle edge, and foot there are other sensory cells responsive to touch and possibly to other stimuli. Of greater popular interest are the auditory organs of bivalves, called otocysts. These are not ears, and their function is probably directive; that is they enable the mollusk to determine the direction of the force of gravity. They are located in the foot and consist of small pouches lined with a specialized sensory ciliated membrane; in each pouch there floats a small grain of calcareous matter. It is supposed that as the mollusk moves the tendency of this small grain of matter to fall on the particular sensory cilia which the animal's movement happens to bring into line with the force of gravity enables him to maintain his equilibrium.

To consider now the important matter of reproduction, we find that bivalves may be either of distinct sex or that one individual may have both male and female organs; that is, the individuals of some bivalve species are unisexual while those of others are hermaphroditic. Unisexuality or bisexuality does not characterize definite groups, since both phases may be present in the same genus. Usually in hermaphroditic species only one sex is ripe at a time.

Mating as observed in many animals does not occur in the pelecypods. The eggs are extruded from the ovaries and either stored away in the brood pouch of the female, as, for example, in the European oyster, *Ostrea edulis*, or cast into the water, as in the American oyster, *Ostrea virginica.* The spermatozoa are similarly ejected from the testes at the proper time. They are attracted to the ova, which they reach by swimming, whereupon fertilization takes place.

When we come to consider the fecundity of some of these bivalve mollusks, we reach figures that are staggering in their magnitude. According to Professor W. K. Brooks,

Ornate bivalve shells from the Gulf of California. The species represented is *Spondylus princeps*

the oyster is well equipped to insure the preservation of its race. He says that an unusually large American oyster will yield eggs enough to fill nearly a cubic inch of space, numbering 60,000,000 on a conservative estimate. A Maryland oyster of good size lays about 16,000,000 eggs to the brood, and if even half of these were to develop into female organisms, we should have, from a single female ancestor 8,000,000 female descendants in the first generation, and 8,000,000 times 8,000,000 or 64,000,000,000,000 in the second generation.

Now, to continue our calculations, if each adult oyster fills 8 cubic inches of space,8,000,000,000,000,000,000,000,000,000,000 oysters would make a mass as large as the earth; so that the fifth generation of descendants from a single female oyster would require more space than eight planets the size of the earth, and this, even if each female laid only one brood of eggs. As the oyster lives for many years, and lays eggs each year, the possible rate of increase is very much greater than that indicated by the above figures.

More recently Dr. Paul Galtsoff, of the United States Bureau of Fisheries, has shown that a single oyster 5 inches long and 4 inches wide produced some 500,000,000 eggs in a season. If half of these produced females and there was no mortality, in the third generation this family would about equal in combined bulk half that of the earth, and in the fourth, 1,200,703 times the bulk of the earth.

The extreme fertility of the oyster means that it must have a high death rate, since otherwise the oyster would soon crowd everything else out of the sea. As it is, man's ingenuity in making use of all natural resources post-haste is rapidly depleting the once seemingly inexhaustible oyster beds. This depletion has already reached such an alarming extent that laws and regulations are being framed in every State along our seaboard to put off the evil day of the oyster's extinction. In Chesapeake Bay alone the annual output has shrunk from 17,000,000 bushels in

1875 to 2,000,000 bushels, the estimated output for 1931. A glimpse at the shell heap (Plate 77) accumulated from a year's output of one oyster-canning plant alone may help the inexperienced observer to realize the immensity of this yield. And man is not the only enemy of the oyster, for while it is in the egg or subsequent larval state it is preyed upon by almost every animal in the sea.

One of the severest restrictions on the work of the zoologist results from the fact that nature has had time and taste for so many experiments. This fact prevents me, for instance, at this moment from writing a simple history of pelecypods from the egg to the adult. Such a history would be fiction and not fact; for there are almost as many histories of Pelecypoda, as there are species in the class, and every history is different in some way from every other. In natural science generalizations are becoming more and more odious.

This much, however, is approximately true of all bivalves: Like all living things, they begin as a single cell; this cell or egg when fertilized (or sometimes even when unfertilized) passes through a series of developmental stages. Of the first three of these stages—a morula stage, a gastrula stage, and a trochosphere stage—we can make a very significant statement; namely, that they are characteristic in a general way of the forms of invertebrate life of lower rank than the mollusks, excepting protozoans and sponges. Thus the trochosphere larva of bivalves closely resembles the larva of worms at a corresponding stage of development, except for the fact that in the molluscan larva a shell gland is present which soon secretes a delicate shell. This similarity of bivalves to lower forms of life when both are in certain larval stages bears striking evidence to the truth of the theory of evolution.

Following the trochosphere the bivalves enter a larval stage which is peculiar to mollusks alone among animals. This is the free-swimming veliger stage, in which the animal acquires a membranelike swimming organ, called

velum (Fig. 48). Thereafter the young mollusk gradually acquires the characteristics peculiar to the adults of the group to which it belongs.

So much for a generalized account of no bivalve in particular—an account which is roughly applicable to all bivalve young, whether they are at once cast loose on the world or harbored in the gill brood pouches of the mother through several stages of their development. When we consider specific pelecypods—the pearly fresh-water mussels found in all North American streams—we find some variant details in the larval story and an entirely new chapter added to it. The fertilized egg of this mussel finds lodging in the brood pouch of the mother and there goes through all the stages mentioned above, including the veliger. Then new changes take place, of which we shall note only two: The ventral edges of the shell may be produced into two incurved hooks armed with spines; and a glandular pouch secretes a single long thread, called the provisional byssus. In this stage the larva is called a glochidium. It remains for some little time longer in the brood pouch and is nourished by a secretion from the walls of the pouch. Eventually it is ejected with its fellow larvae through the excurrent siphon and lies on the river bottom awaiting a victim; for the glochidium, to transform into an adult mollusk, must pass a portion of its life as a parasite on the body of a suitable fish host.

We now see the reason for the incurved hooklike ventral edges of the shell, and for the provisional byssus. The glochidium lies on its back on the river bottom and extends the tiny thread up from between its shells. When this thread comes in contact with a fish, it shortens and the mussel snaps its shell into the host—either into the gills or into the skin or fins. The ferments secreted by the parasite help to bury it in the tissue of the fish, and it is nourished by the juices of its host. In this secure retreat the mussel remains for about ten weeks, undergoing the changes necessary to transform it into a miniature replica

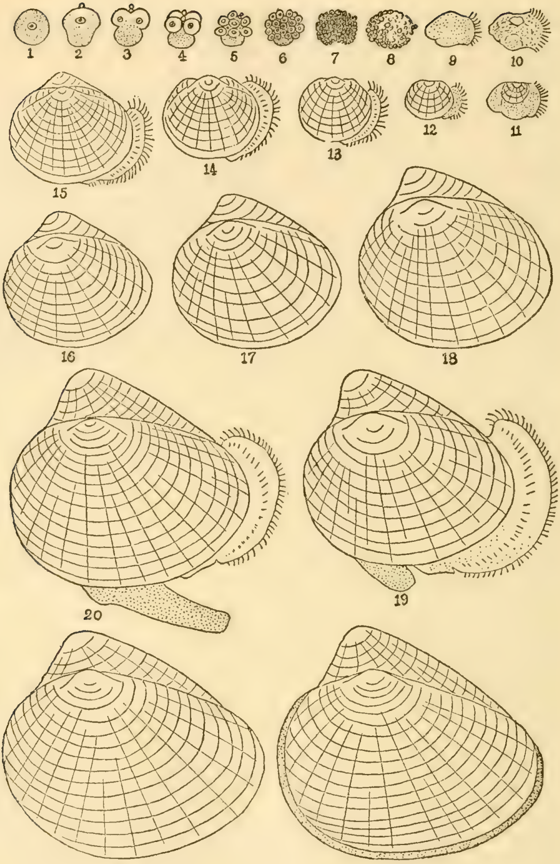


FIG. 48. Development of the East Coast oyster (*O. virginica*); 1, single cell; 6, morula stage; 8, gastrula stage; 9, trochosphere stage; 10, veliger stage; 22, ready for attachment. After Stafford

American oyster of the East Coast

Upper: Shell of *Ostrea virginica*, external and internal views. Lower: Shell heap resulting from one year's operation of a single cannery

Parapholas penita burrowing in hard clay

of the adult mussel. At last fitted for an independent existence the tiny creature sallies forth to the pleasures and sorrows of adolescent and adult life.

Just any fish will not do for a host to the glochidium; most species of our pearly fresh-water mollusks demand a particular sort for their intermediate development. This fastidiousness in mussels presents problems of adjustment truly wonderful to contemplate; some species of them have become dependent upon certain migratory fishes and so spawn only when these fishes make their appearance in the stretch of water frequented by the mussels.

"Like father, like son" is true neither of the appearance nor of the habits of most bivalves. The oyster and many other pelecypods lead a sea-roving life for a time as larvae, but with the coming of adult characters they settle down to a fixed existence. Thereafter they become wholly dependent for food on what wind, wave, and current may waft to them. A larger group, including the black mussels, anchor themselves by the byssus—some permanently, others for varying periods.

There are small and seemingly fragile bivalves of the family Pholadidae which burrow into rocks as hard as granite (Plate 78). They begin by making a tiny entrance and then enlarge the chamber as they themselves grow in size, thus actually inclosing themselves in a rock-bound cell once and for all. While this may seem a confined life, it is probably a comparatively safe one, for the rock protects the frail creatures from their enemies, which would otherwise crush them. These rock-boring mollusks are sometimes sufficiently abundant to become a menace to structures built of reenforced concrete. However, when it comes to threatening human activity they are far surpassed among the mollusks by the wood borers, called shipworms (Plate 79), which are not worms at all but bivalve mollusks. The eggs of the shipworm may be cast into the sea or may be stored in the water tubes of the female to undergo part of their development. But no

matter what the early stages, the larval form—after a period of free swimming—eventually seeks a piece of submerged wood in which to attain its full size. The tiny larva punctures the wood, using its shell as a drill; and once inside it grows apace, adding to its own length and to the diameter of its shell. The outer portion of the shipworm becomes fixed to the inside of the entrance of its burrow, which is guarded by a pair of minute pallets (shelly plates borne on the siphons). The pallets may be shoved into the entrance to close it when danger threatens or when the siphons, through which water is brought to the gills or carried away from them, have been withdrawn. But what tool does a bivalve mollusk have that enables it to honeycomb even hard woods with tunnels? As the animal grows the body lengthens to extraordinary proportions; and the two valves of the shell become practically a pair of hemispherical rasps or files, to which tiny teeth are added row by row. By rotation these rows of teeth are made to file away the wood. The elongate body behind the shell is, of course, shell-less and wormlike. The tiny wood filings ground off by the shell are passed into the mantle cavity and thence—with the mass of minute organisms captured by the cilia of the gills—are forwarded to the palps, and by them transferred to the mouth. Recent experiments have conclusively shown that the shipworm can use certain constituents of the wood as food—its hemicellulose content, at least. These bits are ingested in the cells of the digestive diverticula surrounding the stomach.

The shipworm continues his boring until he reaches his full size, which varies, according to the species, from six inches to four feet six inches in length and from about a sixteenth of an inch to a full inch in diameter. Then he coats his burrow with a porcellaneous lining; and once this is accomplished he becomes entirely dependent upon the food brought to him by the currents created by the cilia of his gills.

The number of young that a shipworm may produce in a season has been variously estimated at all the way from five hundred thousand to three million, depending upon the species; and since shipworms reach sexual maturity in about three months, we may readily account for the outbreaks of these pests, amounting almost to catastrophes, which have been recorded from time to time in various parts of the world. One famous outbreak occurred in San Francisco Bay in 1919 and 1920, when Beach's shipworm, *Teredo* (*Teredo*) *beachi* Bartsch, went on a rampage (Plate 80, upper), and destroyed about $21,000,000 worth of piles, wharves, and docks.

The explanation lies in the fact that two years previous to the outbreak the west coast had suffered from drought, which had so materially reduced the flow of fresh water in the Sacramento and San Joaquin rivers as to permit the invasion of salt water to Suisun Bay. With the sea water came the shipworms, and they found a forest of unprotected timbers to devour.

Losses of less extent due to shipworms are being sustained along the shores of all the seas constantly. Some species have even established themselves in fresh water. From the human point of view all shipworms are bad mollusks; that is, all are destroyers, and no wood in the sea is safe from their attack. I have seen specimens of a cargo of huge mahogany logs (Plate 80, lower) so riddled that it was impossible to cut a board a foot long and an inch thick without a burrow. The mollusks had accomplished all this devastation while the cargo was anchored near the mouth of the Ankobra River in Africa for a period of three months. Lobster pots made of lath and placed in the Bay of Maine have also been completely riddled by these pests. It is interesting to note here that when a large species of shipworm attacks a small bit of wood like a lath, it fails to develop into full size. At maturity it is still dwarfed in all its characters and thus

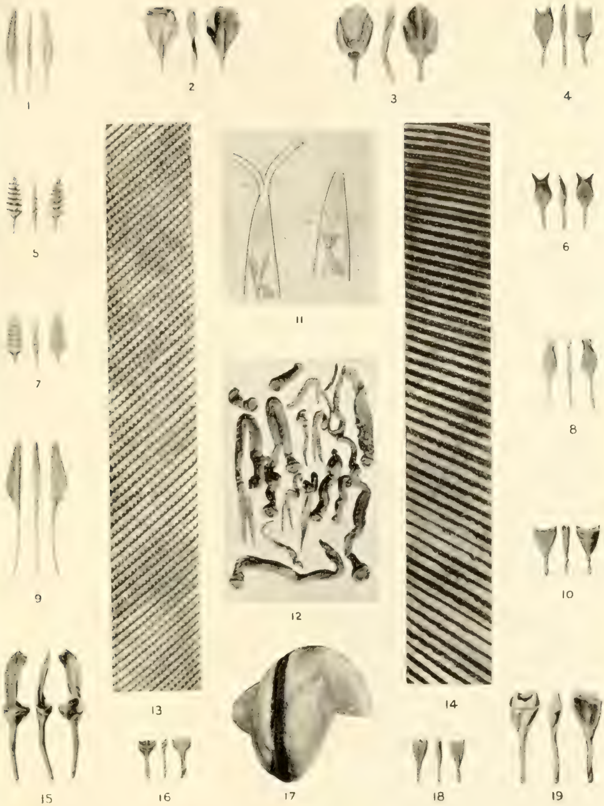
forms a miniature of the normal creature. I have called such stunted forms "stenomorphs."

No wood so far found seems impervious to shipworms. We are often told that this or that variety of wood possesses toxic qualities, which make it shipworm resistant, but when put to the test such woods always fail to stand up. Even the toxic greenheart wood of the American Tropics used for the sills and striking strips of the Panama Canal failed to resist the shipworms; and yet this wood is so poisonous that a man who was immune to berberine—its toxin—had to be brought to the Canal Zone from England to shape the timbers. The very largest of the American shipworms, *Bankia* (*Nausitora*) *dryas* Dall, (Plate 79, Nos. 9, 12, 13, 17), was found infesting the roots of living mangroves in Peru, although mangrove timber had been reputed immune. Floating coconuts also became honeycombed, in spite of the fact that palm wood is said to be free from attack.

I know of but one shipworm whose existence seems to leave a balance on the credit side of man's ledger, and that one lives in far-off Siam, where—so Dr. Hugh M. Smith tells us—it is purposely cultivated in soft wood planted at the mouth of streams. After three months the wood is taken up and split, and the shipworms that have by this time riddled it are collected and sold for food. They are relatives of the oyster, and my limited experience permits me to proclaim them the oyster's equal, if not superior, so far as flavor is concerned.

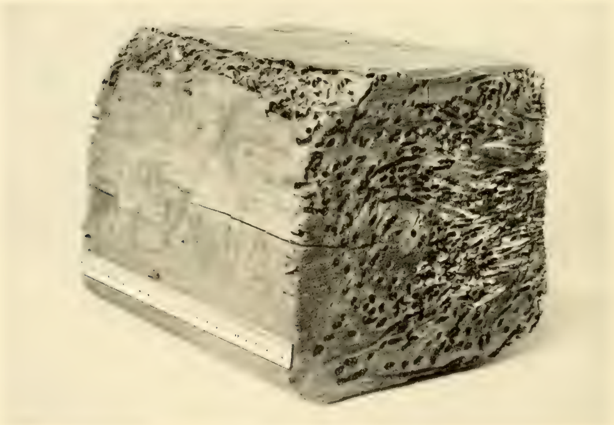
Other groups of bivalves, also, have a predilection for destroying wood—the *Xylophaga*, for example; but none are so completely destructive as those we have just discussed—the members of the family Teredinidae—which rapidly convert into pulp any piece of wood that may be carried to the sea, unless it is protected from their attacks by man.

Still another group of bivalves become what are known as nestlers, because they tuck themselves away into con-



Shipworms

1-10, 15, 16, 18, 19, shelly pallets borne on the siphons of various shipworms, which serve as doors to their tunnels; 11, mechanism for closing door; 12, animals of *Bankia setacea*; 13, 14, cutting files of *Nausitoria dryas* much enlarged; 17, shell of same



Damage by shipworms

Upper: Wharf in San Francisco Bay, which collapsed in 1920 as a result of boring in piles by shipworms. Lower: Piece of mahogany log, completely riddled

venient nooks and sometimes enlarge these to suit their needs. The giant *Tridacna*, whose shell (see Plate 74) is sometimes used as a baptismal font, stretches himself on his back in some coral-reef cranny and permits the reef to grow about him. We are told by Doctor Mayer that coral reefs grow at the rate of two inches a year in the western Pacific. I have several times seen this monster bivalve clamped in a reef, though he was always able to open his shell sufficiently to show the glorious edge of the peacock-colored mantle within.

By far the greater number of pelecypods exhibit a more orthodox behavior in making themselves comfortable and use the foot (Fig. 49) to anchor themselves in the ooze on

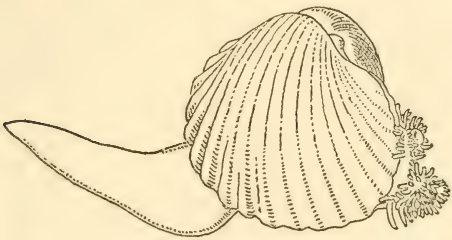


FIG. 49. Cockle (*Cardium edule*) with digging foot extended at left; anal and branchial siphons at right. Modified from Möbius

the floor of stream, lake, or ocean, or to transport themselves slowly from place to place as need or inclination prompts them. In reaches of bottom where sandy mud predominates, you may find the razor clam nicely buried, another exploit which must be credited to the wonderful digging foot (Fig. 50). And on the mud flats, the "mercenary Venus," our hard-shelled clam, or quahog, and the soft-shelled clam must be dug from the hiding places which they themselves have excavated. These and other mollusks, as, for example, *Psammobia florida*

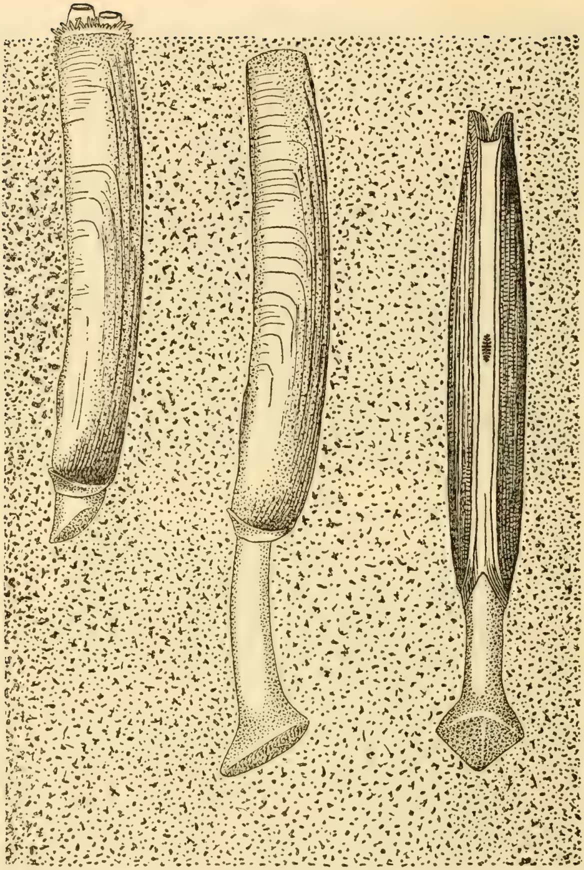
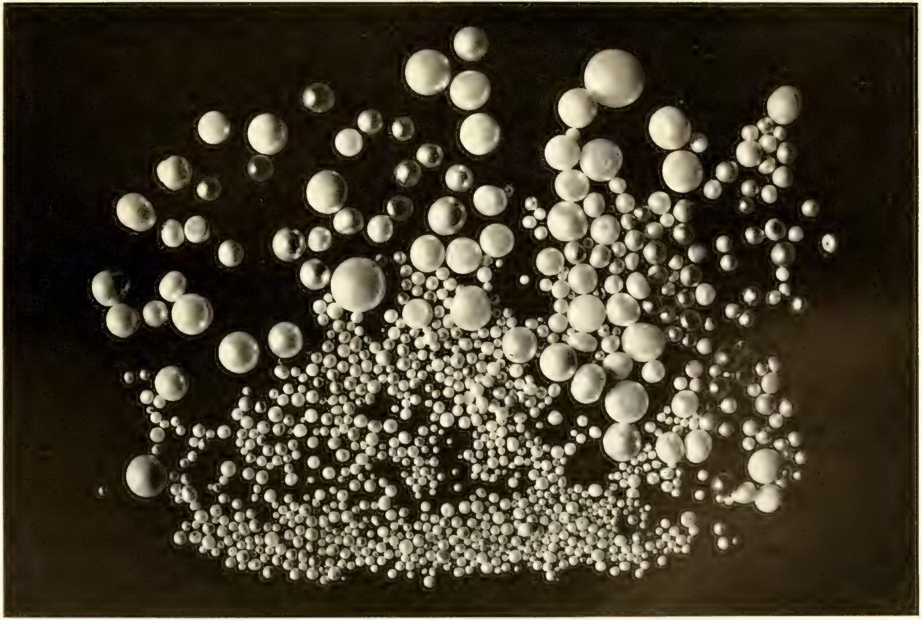


FIG. 50. Razor clams (*Ensis directus*) illustrating use of the digging foot. Left, preparing to extend foot; center, foot extended and expanded; right, anchored foot drawing the animal down. Modified from Drew



Pearls from fresh-water mussels of the Mississippi River. Courtesy of Nature Magazine

Shell of Chinese fresh-water mussel with tin images of Buddha coated with nacre

(see Fig. 46, page 258), dig way down deep to find a snug retreat, and they communicate with the outer world by means of two long siphons.

Not all bivalves are sluggish or slow-moving creatures. If you doubt this statement, try the following experiment along any part of our Middle or South Atlantic coast: Dip up a netful of sand from an incoming wave (using a fine-meshed dip net), and when the sand has sifted out of the net examine what is left behind. You will find a collection of *Donax*. Place them in a dish of water with a supply of sand in the bottom, and instantly the bivalves will right themselves and slip beneath the sand—an excellent object lesson in mollusk speed.

Still more interesting than the *Donax* are the scallops, which dart away by rapidly opening and closing their shells when danger threatens. They are wonderful creatures, provided sometimes, as has been stated, with as many as 120 eyes around the mantle edge. These eyes warn their owners of approaching danger.

It would not be just to the bivalves to leave them without calling attention to the usefulness to man of the group as a whole, for we have already condemned some of its members as harmful—the shipworms. But the useful members make up by far the majority of the group, and of them we will now speak.

The bivalve which ranks highest in dollar value is the oyster. Statistics show that among all the animals of the sea only the herring exceeds the oyster in the annual financial profit which the marine fisheries reap from its sale.

The shells of many bivalves, also, are useful to man. They were once much sought after as ornaments—the pearly ones, especially; and they have often served as money, particularly among primitive peoples. For this latter purpose sometimes small bits instead of the whole shell are preferred. The American Indians from Maine to Texas used to make wampum by cutting and grind-

ing beads from the shell of our hard clam, *Venus mercenaria*, and drilling and stringing them. By selecting the white or blue areas of the shell the Indians were able to make white or blue beads, which, at the time of the white man's arrival, constituted the favored coin of the country. In the Philippines and other parts of the Orient, *Placuna placenta*—the window shell—is much used in windows in place of glass. These shell windows tone down the glare of the tropical sun and are much more restful for the eyes and more serviceable than an equal expanse of glass would be.

No account of bivalves would be complete without a mention of pearls. In Volume 3 of this Series (pp. 217–224) will be found a fuller discussion of pearls than we have space for in this paper, but we can not pass them by here without at least a word.

Pearls, as everybody knows, are found in mollusk shells. They are the result of an effort on the part of the mollusk to seal up an enemy or an irritating substance that has found its way inside the shell or has bored into the animal's flesh. The most perfect spherical pearls usually have as their initial incentive the baby stage of a fluke worm that must live for part of its early life in a mollusk. These young worms burrow into the flesh of the host and live upon it until they have attained a certain growth. The host, to overcome this undesirable parasite, attempts to lock it up by secreting a shelly capsule around it; and if successful it kills the parasite in that way. But having once begun to secrete nacre—the shiny substance of the pearly shell—the mollusk can't stop, and so it builds layer upon layer around the nucleus.

The irregularly shaped pearls known as "baroques" usually begin when a grain of sand or some other hard foreign substance is accidentally forced into the mantle cavity of the mollusk, whereupon the bivalve promptly walls off the intruded matter against the inside of the shell and adds to the wall, layer after layer, the smooth

American cultural pearls

Upper: A perfectly shaped specimen, which cracked as a result of being removed while still immature. Lower: A mishap which resulted when the wax spread upon insertion under the mantle

coating reducing the irritation. Sometimes little water mites related to our chigres attack in large numbers the gills of our fresh-water clams, often causing the irregular "rose" pearls to form. Again, a small fish or crustacean may dart into the mantle cavity seeking protection from some pursuer. This intruder, too, will be walled off, fixed to the inside of the mollusk shell, and covered with nacre until the excrescence so formed develops into a pearl having the shape of the fish or shrimp.

The National Museum possesses some specimens of shells of a huge fresh-water pearl mussel from the Far East, on the inside of which are numerous little images of Buddha, all done in pearl (Plate 82). We are told that these are sold to or bestowed upon pilgrims visiting certain sacred shrines and that they are highly valued by the Orientals as miraculous manifestations of Buddha. These little images are really the forerunners of our "cultural pearls"—the trade name for our artificially grown gems. To produce the pearl images the Buddhist priest inserted a small wooden wedge between the two valves of the mussel, when these were open, to keep them from closing. This made it possible for him to work in the interior. Next he carefully forced the mantle for a little way from its attachment to the inner bottom edge of the shell, and inserted between the mantle and the shell a number of small images of Buddha, stamped in tin, upon the underside of which he placed some sticky substance—probably a bit of beeswax. He then restored the mussel to the pool from whence he had taken it and where he knew it would shortly repair the injury done to the edge of the mantle and would also overcome the irritation produced by the irregular surface of the tin images by coating them with nacre. When he took these mussels from the pool a few months later the images had become fixed to the inside of the shells in just the position in which they had been placed; but now they were nicely

coated with shining pearly nacre—miraculous manifestations of the Great Buddha.

The introduction of foreign elements of various kinds into the shells of live bivalves has been practiced for a long time by many peoples; but the pearls thus produced have usually been inferior, because metals used as a nucleus in such work are apt to cause the nacre to become stained and therefore imperfect.

CHAPTER III

THE TOOTHSHELLS

THE bivalves are headless and toothless, but, as we have seen, quite competent to live their own lives for all that. All the other classes of mollusks, however, have both head and teeth. In some groups the head is well developed and in others extremely rudimentary. As to teeth all the mollusks except the bivalves and a few gastropods are similarly equipped; that is, all of them have in the mouth a ribbonlike organ, called the radula, which is furnished with numerous teeth.

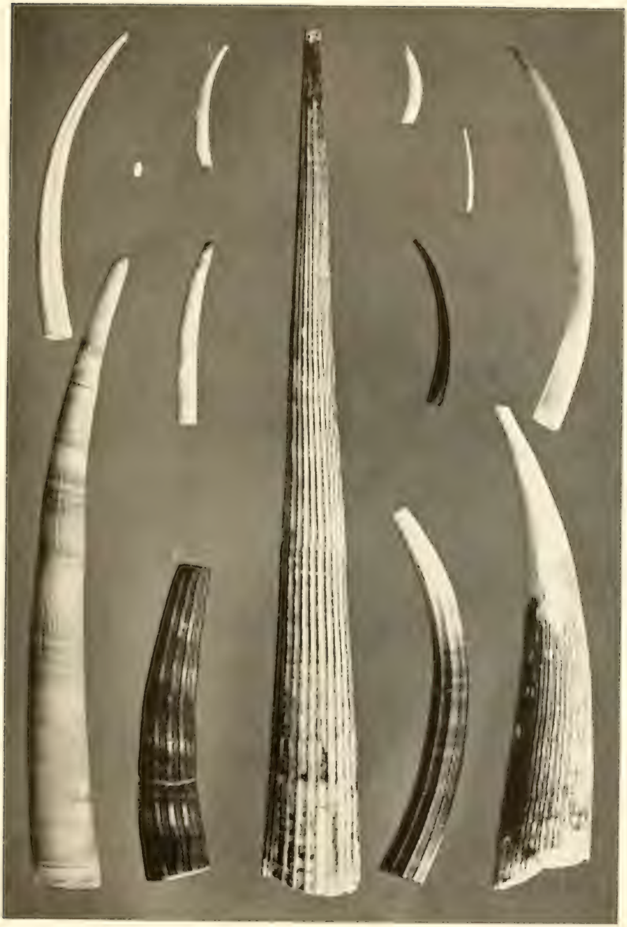
Of a low type of organization, the Scaphopoda constitute a class, not so widely known and alike of less value and of less danger to human economy than any other class of mollusks. But the naturalist who accepts ecoomic value as his criterion of interest will soon find himself doubly betrayed—robbed of the essential equipment for his calling, which is a catholic curiosity avid of every secret in nature, and cheated of finding the very pots of gold for which he seeks; for in the history of science it has repeatedly happened that the most useful secrets, such for instance as the X-ray, have come to light accidentally in the search for truth.

We need not therefore brush the Scaphopoda aside merely because they occupy but little space in the scheme of human economy. Unfortunately little work has actually been done on the soft parts of these animals or on their habits, and there are innumerable facts about their structure and ways of life of which we are totally ignorant. One of the reasons why the scaphopods are so little known

to the public, no doubt, is that they are found only in the sea, and most of them only in the deeps thereof. They range in practically all seas from a little below the low-tide mark to depths of several hundred fathoms. Furthermore, they are little given to traveling but prefer apparently to remain forever in the spot where they begin adult life. The foot with which every scaphopod is provided is used to move the animal, but only directly or obliquely downward. The foot is a burrowing organ, and Scaphopoda means "plowfooted." In burrowing the foot is thrust into the sand; its free end is then expanded to give the mollusk anchorage; and finally muscular contraction pulls the shell headforemost into the hole after the foot. The scaphopod does not bury the entire shell but leaves the hind end of it sticking up into the sea. As the head is thus in permanent darkness, eyes would be useless; so we are not surprised to find that the animal has none.

Toothshell—a name commonly applied to the Scaphopoda—describes the shell or skeleton peculiar to this class of mollusks very well, for it is always notched at the front end. The shell is of a type found in no other mollusk (Plate 84). Secreted by the tubular mantle, it is closed around the animal, but both ends are open. The typical form is long and tapering; but in one genus, *Cadulus*, the shell does not taper regularly but swells out at some point or other in the length, so that some species are cask-shaped and others look like a snake that has swallowed an egg.

Scaphopod shells exhibit but few colors, and there are no gay patterns. Plain white, green, and brown to reddish are all the colors their palette affords. The whites may be chalky or translucent. Not many styles of sculpture are found. The greater number of these shells are smooth, but they may have a few or numerous riblets running along their entire length. The range in size is very great. The largest shell that has come to my notice



Representative scaphopod shells

we dredged during the cruise of the steamer *Albatross* (of the United States Bureau of Fisheries) off the Philippine Islands, at a depth of 281 fathoms. This has a length of about six and five-sixteenths inches, and a diameter of about eleven-sixteenths of an inch. Some, especially in the genus *Cadulus*, are quite minute. For instance, one species has a length of but a tenth of an inch.

In the embryonic stage of the Scaphopoda the shell is flasklike and the upper or posterior end is closed. Shortly after hatching it becomes toothlike, loses the baby shell, and is then open at both ends. Both the anterior and posterior orifices are minute at the beginning but necessarily become larger as the animal grows. As the shell enlarges in diameter at the anterior end, the animal absorbs a portion of the apex so as to make the orifice there larger. The larger end is the front end, and from its generally circular orifice the cylindrical head and long foot are protruded. The function of the orifice at the upper end of the shell is to allow the discharge of the genital products and the wastes of digestion and respiration.

The head of Scaphopoda, if it may be called such, is an egg-shaped projection, which extends into the mantle cavity and at the apex of which is the mouth. This head is surrounded by a rosette of lobes, possibly organs of touch. Farther back are a pair of lobes each bearing many tentacles, which are probably respiratory in function. A number of threadlike "captacula" (Fig. 51) spring from the base of the snout. So called because they catch the Foraminifera and minute bivalve mollusks which form part of the food of the scaphopods, the captacula—true to their name—are thrust in the sand in all directions in search of food, and convey it to the funnel-shaped mouth. Then the masticatory apparatus comes into play. This consists of a tongue or radula, armed with five rows of sharp spines, one in the middle and two on each side. A rotary motion of the tongue enables the spines to rasp off portions of food, which are then passed to the stomach.

The possession of a rudimentary head by this class of mollusks does not involve the possession of a brain. The nervous system of a scaphopod, like that of a bivalve, consists of three pairs of ganglia or nerve centers. Unlike

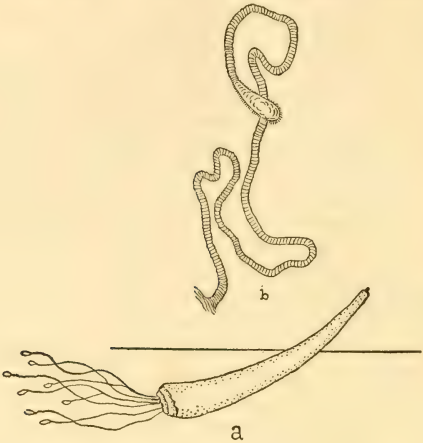


FIG. 51. *Dentalium vulgare;* a, animal in feeding position in the sand with captacula extended; b, one of the captacula greatly enlarged. After Lacaze-Duthiers

the bivalve, the scaphopod has no heart; and the blood does not circulate through well-defined arteries and veins but only through sinuses.

As to whether or not the members of this class possess the senses, indicated in most animals by appropriate organs, the evidence is meager. We do know, however, that the scaphopod is blind. Probably he can hear—to a slight degree, at least—for he possesses numerous otolites or ear stones. These are calcareous and globular and are inclosed in two nearly spherical pouches, lined with

vibratile cilia, which are in constant action and agitate the otolites by an incessant tremulous movement. The lobes at the base of the head are probably tactile organs.

Man today has little use for the scaphopods, but in the days gone by their shells played an important role in the ornamentation of primitive man's dress. Cut in sections they served as beads among the North American Indians. They are likewise said to have been used as the standard of value in trade among the Indians of the Northwest before the Hudson Bay Company substituted blankets for that purpose. A slave was valued at a fathom—from twenty-five to forty of these shells strung lengthwise.

CHAPTER IV

THE SNAILS AND THEIR ALLIES

The stalked eyes and the silvery trail of slime of the garden snail are familiar sights in the experience of all but the most urban of city dwellers; rather repulsive sights, too, due to an aversion to the connotations of the word *slime*. Applied to snails this is quite an illogical aversion, since the garden variety is a cleanly vegetarian with a marked preference for the tenderest of lettuce leaves. A catalogue of the likes and dislikes, taboos and preferences of all the groups of the human race would yield some interesting reading, little of it flattering to human intelligence. Most Americans abhor snails; Frenchmen eat them for the delicacy they are. Yet a Frenchman of Brittany hesitates to eat the fine fruit of the blackberry bushes that line his fields and roads, and for generations white men considered the tomato unfit for food.

But to return to our snails. Those met with in gardens represent but a few among thousands of species of the class Gastropoda, which embraces a larger number of species and of individuals than any other class in the entire sub-kingdom of mollusks. The better-known members of the class go by the popular names of snail, slug, limpet, whelk, periwinkle, sea hare and coat-of-mail shell. They occur everywhere, from the tree tops to the deeps of the sea; they include land forms, water forms, and amphibious forms; they are shelled and shell-less; they are of all sizes from less than that of a tiny pinhead up to a length of two feet, which is the size attained by the big horse conch, *Fasciolaria gigantea* (Plate 86). Finally, they supply

PLATE 85

Shells of Hawaiian tree snails (*Achatinella*), showing the varied color patterns which occur in different species of this genus

mankind with many things, among them, food, dyes, umbrella handles, and—indirectly—diseases.

This matter of gastropod distribution involves some rather curious facts. Civilized man is a ubiquitous animal, capable of living either at the poles or at the Equator. But most other animals lack this ability; they must live in the environment for which they are specially adapted. Thus we find that each area of the earth has its own localized fauna. This is true of the sea as well as of the land, the factors that determine the distribution of species in the sea being temperature, salinity, depth, pressure, character of bottom, and chemical content of the water. Certain groups of mollusks are so delicately adjusted to certain combinations of these factors that they can live under those combinations and no other. The layman would be little apt to guess at the fruitfulness of this fact to the paleontologist. Give him a lot of fossil mollusk shells laid down in some ancient sea and he can readily reconstruct a picture of the bottom and determine such facts as the amount of movement to which the covering sea was subject, its temperature, and salinity. With equal ease the malacologist—student of present-day mollusks—can give a picture of the habitat and name the faunal area from which a collection of recent mollusks have been taken.

Some snails are restricted within almost unbelievably narrow limits. Thus most of the species of the beautiful Hawaiian tree snails, *Achatinella* (Plate 85), are confined to a single island and to a single valley in that island. An aviator who happens to be a malacologist (inconceivable hypothesis), and who makes a forced landing in this valley need only pick a snail from a tree to learn his exact location.

What is perhaps the most restricted range of any animal in existence is that of the dwarf cerion (*Cerion nana*), a species of snails mentioned by Maynard as occurring on the island of Little Cayman, in the Caribbean Sea, in an

area only five or six yards wide by twenty long. Maynard found snails of this species there in 1888; and I found descendants of the same colony occupying practically the same space in 1930, forty-two years later.

The genus *Achatinella*, of Hawaii, the Philippine tree snails of the genus *Cochlostyla* (see Plate 98), and *Amphidromus*, and the garishly colored snails that inhabit the eastern end of Cuba, *Polymita picta* (see Plate 103), offer exceptional problems to the student of genetics and heredity because of the remarkable differentiation from the typical form which has taken place in them. Each in fact occupies a territory that may be considered a glorified laboratory, in which nature, beginning in comparatively recent times, has been experimenting to produce the products seen in our pictures. Each one of these groups enables the knowing eye to discern the factors involved in its differentiation. The workshops are still present, and the tools of hybridization, isolation, and fixation are still at hand.

Although most marine snails are closely circumscribed in habitat, it is possible to find some of them living above the high-tide line of the sea, for example, at Koko Head, Oahu, Hawaiian Islands. The key to this paradox lies in the action of the breakers. They have cut away the edge of the island and produced sea cliffs of considerable height, from the top of which the land slopes back gently, with many pits and depressions in its lava surface. The long rolling waves break against the cliff, smothering the space above them with spray and spume to varying heights, depending upon the condition of the sea; though even with a quiet sea the swell breaks constantly over the rim. This spray carries with it larval creatures of many kinds and strands them in the pools and puddles, so that they establish themselves there. One can find quite a molluscan marine fauna and many other animals flourishing way above the level of the sea, each wave bringing a new supply of water and food to them.

The two largest of the gastropod shells. Left, horse conch (*Fasciolaria gigantea*); right, *Fusus proboscidiferus*

Longitudinal section of the shell of *Strombus gigas* illustrating the spiral coiling

Two other groups of marine gastropods (to be discussed later), have won for themselves a larger horizon than that of most of their relations. They have become adapted to a free-swimming existence and spend their lives roaming the deeps.

Structure and Functions

The shells of gastropods are like human nature—infinite in their diversity. The more usual forms are in reality cones, which have been coiled to economize space. Each of them begins as a tiny capsule, to which constant additions are made at the open or mouth end until it attains its full size (Plate 87). The shells are almost always spirally coiled, usually to the right, but not always so. Right-handed species very rarely take a left-handed turn, and the left-handed forms are equally careful about their behavior. Some, however, like *Amphidromus*, are not so particular; and offspring from the same mother may include both dextral and sinistral individuals. Some species, like the limpets (Plate 88, No. 9), seem to have no whorls, but only a cuplike dome; though many limpetlike forms show the tiny coils in their baby stages.

To paraphrase Napoleon, one picture is worth ten thousand words describing the surfacing of the spiral shells of gastropods. Plate 89 shows some of the many different kinds of surfaces found in the shells of the genus *Murex* alone—polished, granular, spined, knobbed, ribbed axially or spirally and the ribs varying in magnitude from hairlike to cordlike; or the sculpture may consist of incised elements of varying strength. Why this variety? Some of the features undoubtedly add strength to the mollusk's housing and others increase its defense efficiency against the ravages of fish and other enemies. But the wherefore of many remains a mystery to man.

A group of "worm" shells from Bermuda—*Vermetus lumbricalis* (Plate 90)—betrays a curious departure from the norm of spiral shells. These mollusks begin with

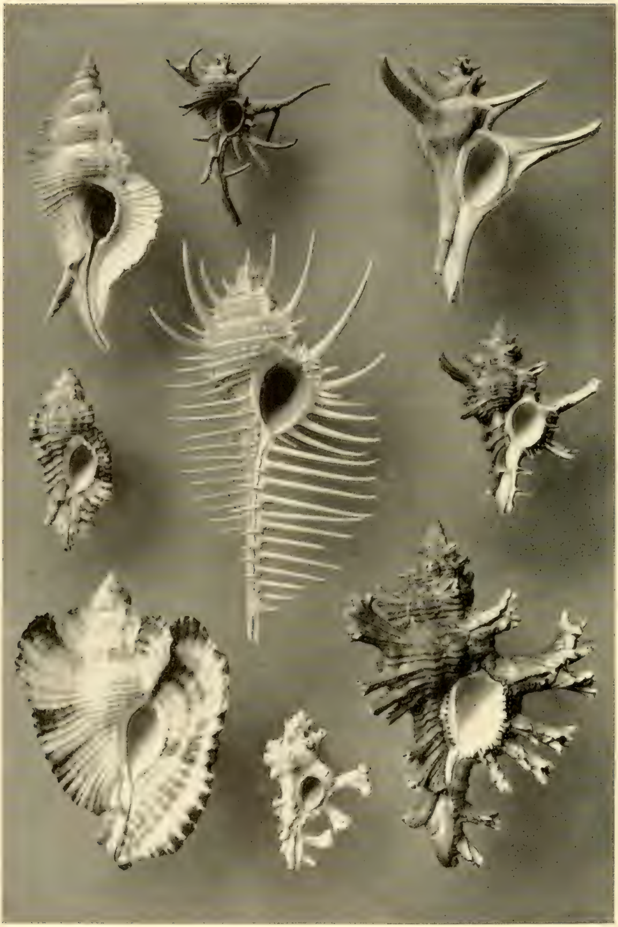
orthodox, spirally coiled shells; but they break with convention at last and assume the form shown in the illustration.

Some shells plume themselves with borrowed feathers. The marine snail *Xenophora*, appropriately known as the collector, has acquired the habit of bedecking himself with the empty shells of other mollusks as well as with sand grains, bits of coral, and similar detritus from the sea bottom. The collector affixes these decorations into his shell near the suture as the shell is secreted (Plate 91). This habit probably began as a protective measure, most likely when *Xenophora* first evolved; for no matter what species we examine—even one that seems free of such bedecking—we will always find at least a trace of shell fragments on the early turns. Apparently mollusks, like men, find it difficult to overcome an acquired habit.

There is another character of the gastropod shell structure which presents fascinating features and problems. I refer to the aperture. The shape of this reveals an endless series of modifications in the different species, some of which are shown in Plate 92. The aperture, of course, is the gate of the mollusk's fortress; and the security thereof is no greater than the effectiveness of the guard at this gate. Many gastropods—terrestrial, fresh-water, marine—have a kind of door, called operculum, which closes them in the shell. Some supplement this door with other defensive devices, a number of which are shown in Plate 93. All these devices are based upon the thickening of the edge of the aperture or a part thereof, or upon its contraction, or upon the possession of lamellae.

The gastropod carries his door on his foot. This is the most logical position possible for the structure, since it is the foot that brings up the rear when the animal retreats into his shell, and so permits the door, or operculum, automatically to close the aperture when the foot has passed through it. Some authorities offer the interesting suggestion that the operculum represents the equivalent of

Representative gastropod shells, showing great range of shapes



Shells of *Murex*, to show different kinds of surfacing in a single genus

the second valve of the pelecypods; that is, that the gastropods have evolved from a bivalve form, one valve becoming the twisted cone and the other the operculum.

The opercula in gastropods almost equal their shells in variety of surfacing, as is indicated in Plate 94. In its least specialized form, the door is a simple plate of chondrin, a substance allied to the material of which a crab's shell is composed. This plate is present as the basal element in all opercula, although in some it is so thin that it forms a mere film.

Incidentally the operculum of some groups of gastropods revives the oft-asked question as to why some things in nature are so beautiful. The under side of the operculum in the groups to which I refer, that is, the part attached to the foot and so permanently hidden during life from the eyes of man and beast, may be wonderfully banded with rays of brown and green. Why is it so beautiful? Evidently there is no reason at all.

The closing of the door to evade enemies that may camp at the doorstep indefinitely to await its opening, has resulted—at least, so one may assume—in the development of all sorts of devices that will enable the animal to breathe while the closed door defies the would-be invader. In the American family of operculated land shells—the Annulariidae—these devices include a simple slit in the upper angle of the aperture, a simple puncture, and a perforated tube or siphon too fine to admit the undesirables.

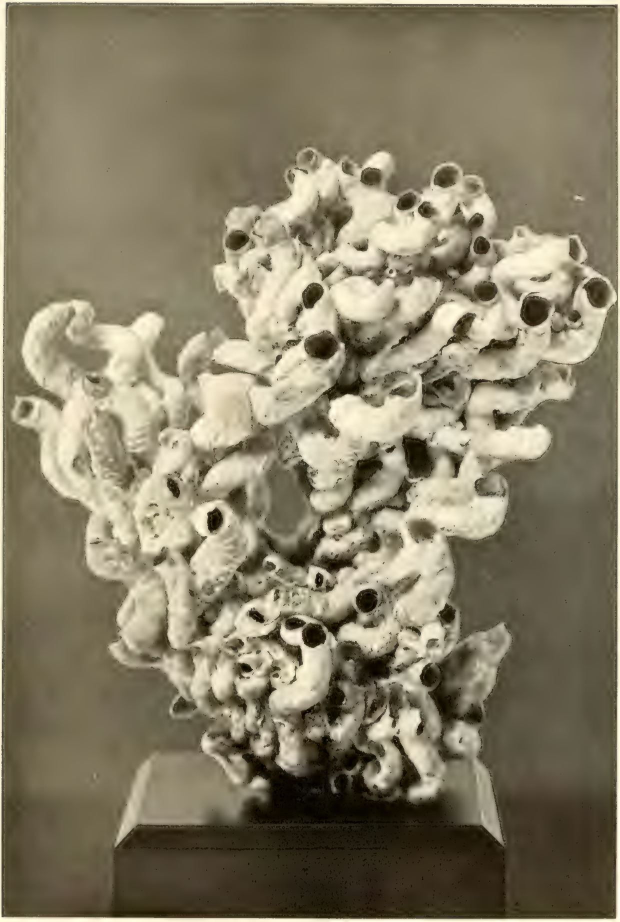
However, not all gastropods are equipped with a door to close the shell or even a supplementary device to keep out undesirable visitors. This lack likewise presents the problem of keeping in moisture, notably to certain tropical land forms, during the parching days of a tropical dry season. Many of the species so handicapped have solved this problem by spinning, or rather, secreting, an epiphragm. The epiphragm in its simplest form is nothing more than a film of dried slime. In some snails, however,

it is supplemented and strengthened by the addition of lime salts. The epiphragm hermetically seals the animal within its shell when it aestivates and prevents the loss of the moisture needed for its existence. The epiphragm is dropped when the animal resumes an active existence at the beginning of the moist season. Plate 95 shows *Cepolis ovumreguli*, from eastern Cuba, tucked away in an old palm leaf for a dry spell.

Incidentally, some gastropods are capable of even greater refinements of spinning than that just described. Like spiders they spin threads by which to suspend themselves, in mid-air, from a shelf of rock or from the roof or side of a cave. This capacity seems to play some part in the love-making of the slugs of the species *Limax maximus*. After executing a nuptial dance, a pair of these slugs will spin a thread and by it drop free from some overhanging support during mating. After the performance they will climb back to solid ground via the thread.

The ornamentation of the gastropod shell is not confined solely to sculpture, for many shells are wonderfully colored, as the color plates in this chapter show. No matter what hues may be present or how intricate the pattern they form, I have yet to see them so assembled or combined as to sound a false note. The commercial artist might well appeal to shell coloring and shell sculpture for models of beauty in tone and form. So far as I am aware, only one people—the Japanese—are awake to the rich treasures presented in this field.

It may be that the wonderful coloring of some species of gastropods helps to conceal them from their enemies. Yet in many species we know it can serve no purpose. The beautiful shell of the tentshell (*Oliva porphyria*), in the Gulf of California (see Plate 72, No. 6), is completely hidden by the animal's mantle. I recall my frequent chagrin in turning over coral blocks in the shallow reaches of the Philippine seas in quest of nudibranchs—beautifully colored sluglike gastropods, usually



A departure from the norm in so-called worm shells (*Vermetus lumbricalis*) from Bermuda

Shell of *Xenophora*, the collector, with decoration affixed during growth

shell-less in the adult stage—on seeing some gorgeous creature slowly retreat into a shell and so proclaim itself a cowrie. All the cowries, prodigal of beauty, wrap the glory of their shells in a mantle which itself might dispute with anything in nature for the crown of loveliness.

So much for the more usual type of shell in the Gastropoda—the spirally wound cone with its infinity of variants. Some gastropods, for example certain slugs, have no shell at all; or, at best, they have but a small internal shelly plate. As the adult oyster has dispensed with a useless foot, so have these slugs dispensed with a useless shell. This is a common phenomenon in nature—to discard what has become superfluous—so that we are not surprised to encounter it in some of the gastropods. However, we may find cause for wonder in the extraordinary modification of the molluscan shell exhibited by the chitons of the subclass Amphineura—the coat-of-mail shells (Plate 96). In the chitons the shell consists of eight pieces, or plates, which cross the animal like the armor of an armadillo and completely protect it. The plates are imbricated, that is, slightly overlapping, and articulated and may be smooth or variously sculptured. They grow out of a section of the mantle called the girdle, which may be a narrow band or may cover the entire upper part of the animal.

The shell of a chiton is further distinguished by the possession of eyes. According to A. H. Cooke, *Corephium aculeatum* has as many as 12,000 eyes, of which more than 3,000 are found in the head plate. The largest known chiton eyes measure a thirty-fifth of an inch in diameter. It is possible that these "eyes" have some value as visual organs, for many of them have cornea, lens, pigment layer with iris, and retina; however, their power of vision must be low.

Chitons are all dwellers in the sea, ranging from the high-tide level to the deeps. When dislodged from their anchorage they curl up like an armadillo or a pill-bug, but

if undisturbed they will eventually uncurl and move off to some hiding place.

Gastropods are so called because the better known kinds appear to walk on their abdomens (Fig. 52). Scientific attempts at descriptive nomenclature have rarely

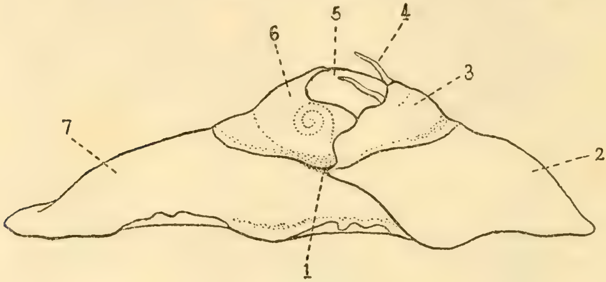


FIG. 52. *Natica josephina;* 1, exhalant orifice; 2, propodium, or forefoot; 3, part of propodium extending over shell; 4, tentacles; 5, shell; 6, part of metapodium extending over shell; 7, metapodium, or hind foot

been so successful: certainly "bellyfooted" is an apt name for a snail. Like everything else in the gastropod cosmos, however, the foot is subject to innumerable modifications in different groups, resulting, of course, from the wide range in methods of progression in the class.

Thus in the genera *Melampus* and *Pedipes*, a groove separates the fore part of the foot from the middle part. When moving the animal seems to step along: it extends and fixes the fore part then draws up the rest like a leech, moving—so to speak—in a series of loops. In many of the annulariids the sole is divided lengthwise by a groove, and such species progress by alternately moving the two sides. The resultant motion in some is, in miniature, like the swaying of an elephant, or the waddling of a very fat puppy but of course much slowed up. The broad sole of the foot in the sea-ears (*Haliotis*, Plate 97, upper left),

PLATE 92

Shells of land, fresh-water, and marine gastropods, to show differences in shape of the aperture

Shells of land and marine gastropods, to show kinds of armature of the aperture

limpets, and chitons enables these mollusks to secure a firm hold on their support by suction—so firm that it is almost impossible for a man to dislodge one of the larger members of these groups. In fact, there are records of men having been captured by the mollusks, instead of the reverse. The huge sea-ears or abalones have not only a wonderfully iridescent pearly shell but also a toothsome flavor, which, before the supply became decidedly limited, caused them to appear regularly at the fish marts of the California coast towns. It seems that more than one stroller by the sea who was acquainted with sea-ears as a market delicacy has happened upon one at extreme low tide fastened to a rock, and unaware of the amazing strength with which the foot can hold on to its place of attachment, has slipped a hand under the slightly raised shell to pull it off. Instead of succeeding in this intention the luckless man had his hand caught under the clamped-down shell. The more he struggled the tighter the mollusk would hold on. The incoming tide would in time put an end to struggle and life alike, and only then would the weary *Haliotis* loose its hold. The bruised fingers of the drowned victim would tell the tale of the battle for life, in which the mollusk won.

These mollusks that cling tightly to rocks, from which, once they have clamped down, only a knife can pry them loose, may be readily dislodged from their anchorage by a sudden jar or sidelong shove, if they are caught unawares before they contract.

Some gastropods use the foot as a float; that is, they expand it in such a way that it becomes broad and flat, and exposing the sole to the air they move about at the surface in an inverted position. *Physa* and some *Lymnaea*, fresh-water mollusks that often grow in aquariums, frequently indulge in this pastime.

In many gastropods the foot has been transformed into an efficient swimming organ. Notably is this true of two subclasses, the Pteropoda and Heteropoda, the free-

swimming groups which have been referred to earlier in this chapter as rovers of the sea. Their names mean "wingfooted" and "diversefooted." The Pteropoda (Fig. 53) have the anterior lobes of the foot developed

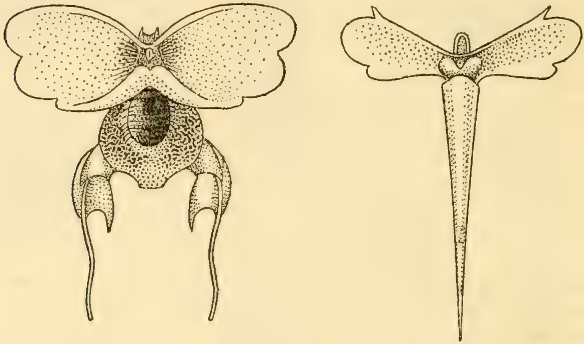


FIG. 53. Representative Pteropoda, with foot transformed into swimming wings. Left, butterfly pteropod (*Hyalaea limbata*); right, *Creseis subula*, with long shell. After De la Sagra

into two broad thin winglike organs with which they swim at or near the surface.

The modification of the heteropod foot (Fig. 54) for swimming is of a different sort; the entire foot has become a sort of median fin, and the animal swims back downward.

The Pteropoda with their wingfeet frequently match the butterfly in brilliance of coloring. Though small, these gastropods are so numerous that at times they cover the surface of the sea for miles and constitute the main article of diet for many fishes and cetaceans. The shell that incases the pteropod is thin, frequently a mere film, usually transparent as glass and often even more fragile. When one captures these creatures in a plankton net and liberates them in a bowl of sea water for study, one does not always feel sure that they are actually present

in the dish. Their extremely delicate structure suggests often but a bit of jelly, and that is so transparent that it fails to obstruct the view of whatever lies beyond it.

No discussion of the gastropod foot would be complete that did not touch on one matter that must surely have excited the curiosity of everyone who has seen a slug

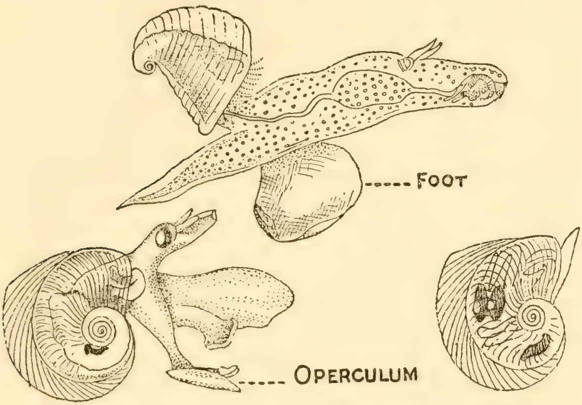


FIG. 54. Representative Heteropoda. Upper, *Carinaria;* lower left, *Atlanta;* right, same withdrawn into transparent shell. After Eydoux and Souleyet

drawing his silver trail along a garden path: How does he make the trail and why? It is made by a secretion from glands in the foot of land mollusks, and its purpose seems to be to smooth the passage of the snail. In other words the snail is his own road maker and carries with him a superior liquid surfacing. The silvery glint of the trail comes out when the secretion dries after the snail has passed. "Go slowly, go surely, and you will leave a brilliant trail," admonishes the snail.

Because a certain gastropod lives in water we need not conclude that he breathes by means of gills; nor because

another lives on land that he has lungs. Among the gastropods there are lung-breathing aquatic forms and there are also gill-breathing terrestrial forms. The genera *Lymnaea*, *Physa*, and *Planorbis* spend their lives in fresh water, yet they must come to the surface periodically to fill the lung with air. They are like the whales, which are born and live in the water, yet breathe as do all other mammals.

But the exchange of an aquatic home for a terrestrial one does not necessitate the exchange of gills for lungs. The traveler in Florida or the West Indies can scarcely have failed to notice the countless numbers of snails (genus *Tectarius*) clinging to the rocks well above high-tide level. Our *Littorina irrorata* climbs up on the beach grass at the Virginia capes, while *Littorina rudis* decorates the northern rocks above high tide, and *Littorina angulifera* clings to the mangrove roots away above the water mark along our Florida Keys. All of these are gill breathers, yet they seem to shun the water, probably visiting it only often enough to keep the gills moist. Herdman showed that marked specimens of *Littorina rudis* did not change their position on the rocks for thirty-one days. What is more, all the gastropods mentioned are, as a rule, exposed to the blazing rays of the sun; so their capacity to make a minimum of moisture go a long way becomes truly phenomenal.

The future physiologist will find plenty to occupy him in clearing up the secrets of breathing in many gastropods. The land operculate gastropods—which make up several families—are structurally related to the gill breathers, yet they never seek the water; and many species of them live attached to limestone cliffs, where they are not infrequently exposed to the blazing rays of the sun.

All the land and fresh-water mollusks that have no operculum breathe by means of a lung cavity or true lung. These constitute the group known collectively as the Pulmonata. The lung in the Pulmonata is by no means

the complex organ of respiration designated by that name in the Mammalia; it is rather a pouch, simple or with complex folds, lined with a mucous membrane which is richly charged with fine blood vessels.

Some gastropods, for example the apple snails (*Ampullaria*), have both gills and lung and can make use of both or either for respiration. On the other hand some of the nudibranchs—marine gastropods which have no shell in the adult stage—have neither gills nor lung, but breathe through the skin.

Nature has contrived no more successful organ for the getting and grinding of food than the tonguelike radula, armed with teeth, which is characteristic of mollusks higher than the Pelecypoda and to which we have already had occasion to refer in discussing the Scaphopoda. The radula is present in all gastropods with the exception of the superfamily Gymnoglossa, some of which live parasitically in starfishes, sea urchins, and their kin and so have no need for a food-capturing organ, while others have a suctorial proboscis to take the place of a radula.

Even when present in gastropods the radula is not always the only organ of mastication. Many species of this class of mollusks have jaws (Fig. 55) with which to bite off and partly crush their food. But the radula usually plays the leading role in food getting and food grinding.

This organ lies upon a thick muscular cushion which is situated on the floor of the snail's mouth (Fig. 56). A tough membrane covers its under surface, and it may bear many rows of fine teeth. The radula in operation has been likened to a cat's tongue when that animal is licking, but its motion is much slower. During feeding the snail can press this organ against the roof of his mouth, or he can advance it to the jaws, or he can even project part of it beyond the jaws. The radula does not bite the food taken into the mouth and thus mince it, but rasps it to pieces as a file rasps iron. Watch almost any fresh-

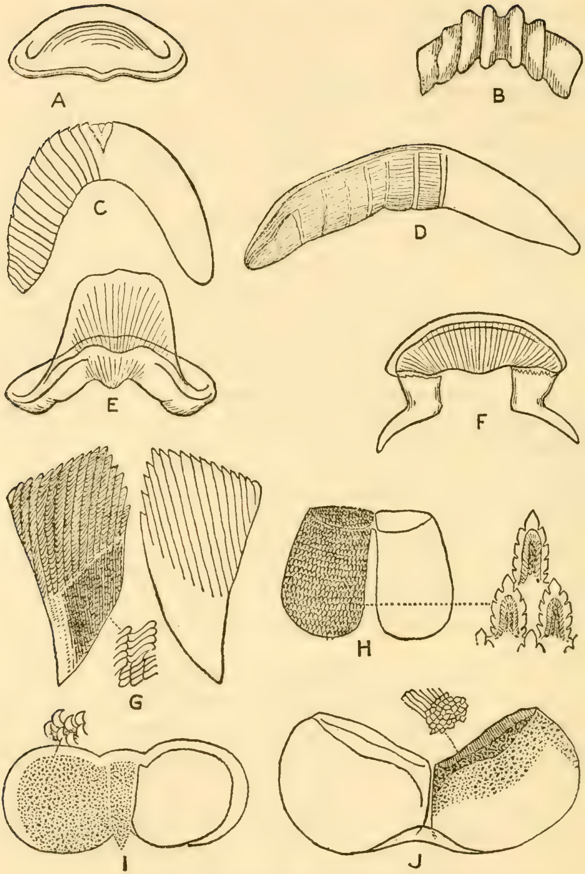


FIG. 55. Jaws of various gastropods to show differences in shape and structure. All much enlarged. After Cooke

water snail cut a swath through a thin growth of confervae in an aquarium and you will see the operation of the radula.

Great differences occur in the width and length of the radula. In some, like *Littorina*, it is coiled up like a watch

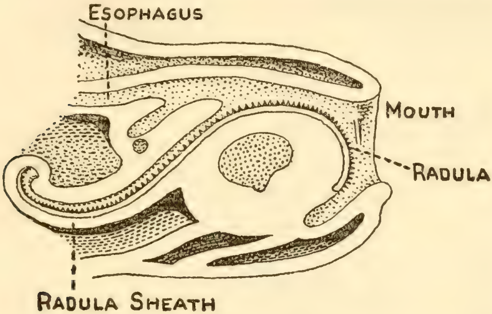


FIG. 56. Longitudinal section of head of a gastropod. After Lang

spring at its posterior extremity and is several times as long as the whole gastropod.

The snail is more fortunate than man, who has to depend on just two sets of teeth to last him through life; the radula is inclosed at its posterior extremity in the radular sheath, and in this sheath new rows of teeth are constantly developing and slowly moving forward to replace the worn-out teeth at the outer end.

Students of mollusks have agreed upon a classification of the radula teeth (Fig. 57). They call the central tooth the rachidian; the tooth (or, perhaps, teeth) on each side of the rachidian the lateral; and that or those beyond the lateral, at each end of the radula, the marginal tooth or teeth. As suggested above, the lateral teeth may occur singly (one on each side of the rachidian tooth) or in a group of several (one group on each side); and the same

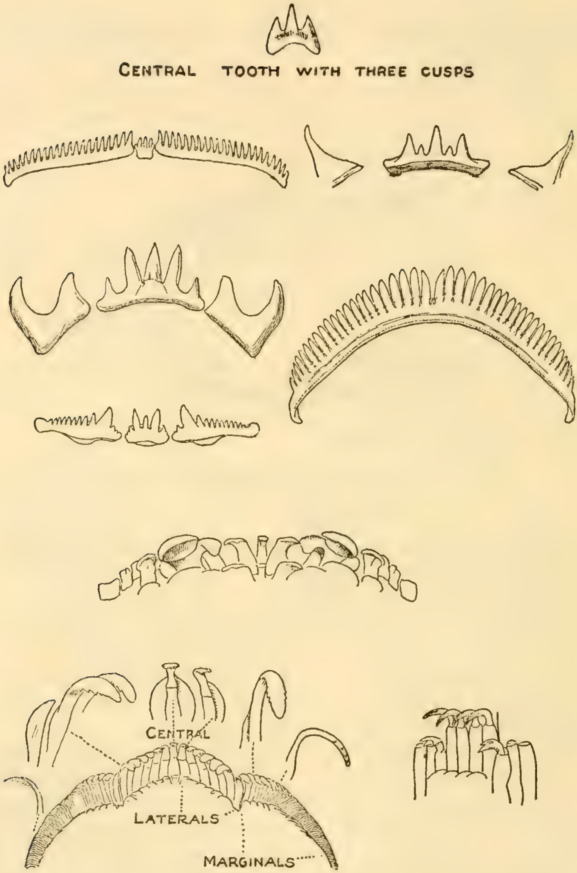
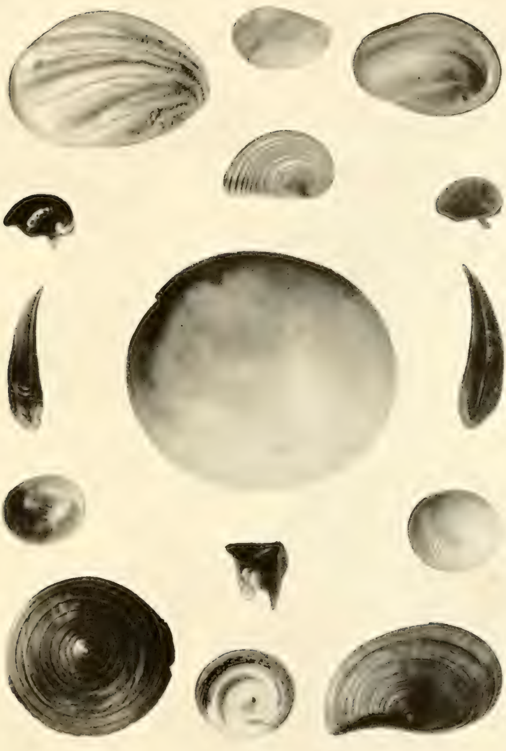


FIG. 57. Single rows of teeth from the radulas of gastropods, illustrating variety of structure. Much enlarged. After Cooke



Opercula of various gastropods, illustrating variety in shape and surfacing

Cepolis ovumreguli aestivating in a palm leaf

is true of the marginal teeth. A. H. Cooke gives us a very lucid picture of the arrangement of the teeth: "The teeth on the radula are almost invariably disposed in a kind of pattern, exactly like the longitudinal rows of colour in a piece of ribbon, down the centre of which runs a narrow stripe, and every band of colour on one side is repeated in the same relative position on the other side."

The number of teeth on the gastropod radula varies from 1 to possibly 750,000, depending on the species. Again to quote Cooke:

> When the teeth are very large, they are usually few in number, when small, they are very numerous. In the carnivorous forms, as a rule, the teeth are comparatively few and powerful, while in the phytophagous genera they are many and small. Large hooked and sickleshaped teeth, sometimes furnished with barbs like an arrowhead, and poison-glands, are characteristic of genera which feed on flesh; vegetable feeders, on the contrary, have the teeth rounded, and blunter at the apex, or, if long and narrow, so slender as to be of comparatively little effect. Genera which are normally vegetarian, but which will, upon occasion, eat flesh, *e.g.*, *Limax* and *Hyalinia*, exhibit a form of teeth intermediate between these two extremes.

Fig. 58. A tooth from the radula of *Conus imperialis*, showing barb and poison duct (x 50). After Cooke

That snails' teeth may carry poison glands (Fig. 58) will probably surprise most inhabitants of northern countries, for the family which is thus distinguished is confined to tropical seas. The natives of New Guinea have a wholesome dread of the bite of *Conus*. And well they may, for the poisonous nature of the bite of certain species of this genus is well authenticated, as the following instances noted by Cooke, all of which occurred on certain islands near New Guinea, in the South Pacific, will indicate:

Surgeon Hinde, of the British Royal Navy, saw a native on the island of Matupi (New Britain) who had been bitten by a *Conus*

geographus and who had at once cut small incisions with a sharp stone all over his arm and shoulder. The blood flowed freely, and the native explained that had he not taken this precaution he would have died.

According to Mr. J. Macgillivray, who, in turn, quotes the natives of Aneityum Island, *Conus textile* (called *intrag* by the natives) spits poison upon its victims from a distance of several inches. Two cases of bites from *C. textile* were brought to this gentleman's notice, one of which terminated fatally after gangrene had set in.

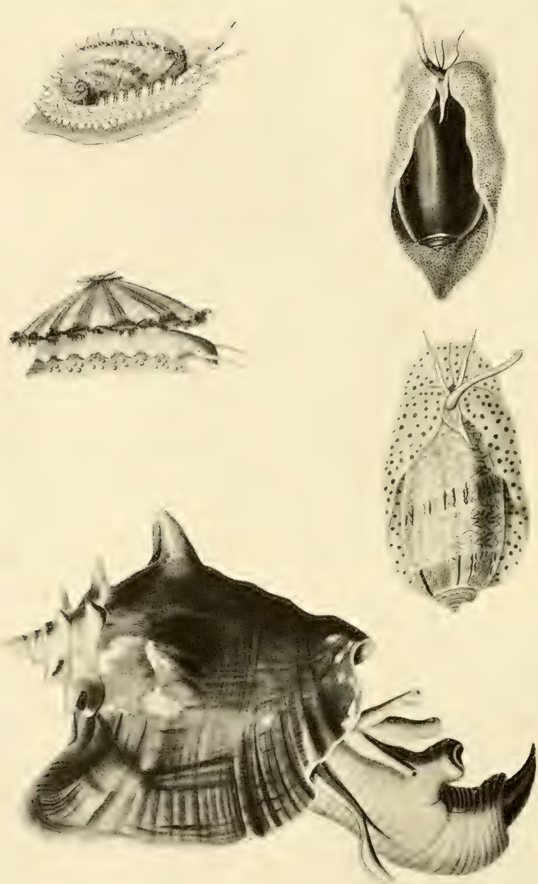
Sir Edward Belcher, when in command of the *Samarang*, was bitten by a *Conus aulicus* at a little island off Ternate, in the Moluccas. As he took the creature out of the water it suddenly exserted its proboscis and inflicted a small, deep, triangular wound, causing a sensation similar to that produced by the burning of phosphorus under the skin. This wound was succeeded by a water-filled vesicle.

The digestive system of gastropods, of which the radula happens to be the most distinctive member, may for convenience be divided into mouth, esophagus, stomach, and intestine. The mouth in different species varies from a mere slit without strongly differentiated lips to a long, strong proboscis.

The radula and other food-getting organs of gastropods are, of course, adapted in each species to the feeding habits of that species. The wide range of the class would indicate a great variety of diets, and actual observation confirms such a surmise. Some of the marine forms, which are more or less sedentary in habit, feed on the minute free-floating life of the sea, as do the oysters and their relatives, and in much the same way: the plankton is strained from the water by the cilia of the gills, which then convey it to the mouth.

J. H. Orton found that *Crepidula*, a marine gastropod, feeds as do pelecypods. The radula in this genus, he says, has changed from a rasping to a grasping organ and is used for conveying the collected food masses to the mouth.

Coat-of-mail shells, chitons. The plates are overlapping and articulated



Gastropods in their shells. After various authors

While collecting many sedimentary marine gastropods, I have observed that their habitats generally suggest long-continued and undisturbed occupation. The old belief that these creatures were nocturnal in their feeding, moving about for that purpose and returning to their abodes by day, seems far fetched, to say the least. Plankton feeding, coupled with the sedentary habit, seems a much more rational explanation, although, of course, this method of feeding is by no means universal among marine gastropods.

The group popularly known as slugs would appear to include both epicures and gluttons. Cooke says of one species: "*Arion ater*, the great black slug, although normally frugivorous, is unquestionably carnivorous as well, feeding on all sorts of animal matter, whether decaying, freshly killed, or even in a living state. It is frequently noticed feeding on earthworms; kept in captivity, it will eat raw beef; it does not disdain the carcasses of its own dead brethren. . . . Indeed it would seem almost difficult to name anything which *Arion ater* will not eat. . . . A specimen kept two days in captivity was turned out on a newspaper, and commenced at once to devour it." It seems that this specimen was also induced to eat Pears' soap, though with reluctance.

Some species of slugs common to England are most destructive in gardens, feeding entirely on chlorophyll-bearing plants; but others feed exclusively on lichens, a fact which would suggest that not all slugs are the enemies of gardeners, and that while it is a protective measure to eliminate certain species, others should be encouraged.

Slugs betray a fondness for flowers and have been known to exercise considerable ingenuity to reach them in spite of man's precautions. Cooke quotes an observer who actually saw many little slugs suspending themselves by slime threads from the rafters and descending on the spikes of the beautiful orchid *Odontoglossum alexandrae*; and thus many spikes, although thickly wadded round

with cotton wool (which the slugs could not travel over) and growing in pots surrounded by water, were lost.

But our authority cites the following as perhaps the most singular instance of a liking for a particular food: In a London publishing house, slugs were observed, during a period of nearly twelve months, to have fed almost nightly on the coloring matter in certain book covers; and though the trails were often seen over the shelves, and cabbage and lettuce leaves laid down to tempt the creatures, they continued their depredations with impunity for the time above mentioned.

Slugs will sometimes bite their captors' hands. Cooke records some instances of this:

> Mr. Kew relates that a *Limax agrestis*, on being stopped with the finger, while endeavoring to escape from the attack of a large *Arion*, attempted to bite fiercely, the rasping action of its radula being plainly felt. According to the same authority, probably all the slugs will rasp the skin of the finger, if it is held out to them, and continue to do so for a considerable time, without however actually drawing blood. While Mr. Gain was handling a large *Arion ater*, it at once seized one of the folds of skin between the fingers of the hand on which it was placed; after the action of the radula had been allowed to continue for about a minute, the skin was seen to be abraded. Another specimen of *Arion ater*, carried in the hand for a long time enclosed in a dock leaf, began to rasp the skin. The operation was permitted until it became too painful to bear. Examination with a lens showed the skin almost rasped away, and the place remained tender and sore, like a slight burn, for several days.

In order that the reader might connect, in a very general way at least, the structures and functions of mollusks with those of vertebrate animals (with which he is more familiar), we touched upon the nervous and circulatory systems of the Pelecypoda and Scaphopoda in the chapters dealing with these groups. To discuss these systems in the Gastropoda, however, would involve us in too many technicalities. But it may be of special interest to know that malacologists have largely depended on the nervous system to divide the class Gastropoda into two subclasses: Streptoneura and Euthyneura.

PLATE 98

Shells of Philippine tree snails (*Cochlostyla*), showing variations in color pattern, size, and shape which occur in different species of this genus

Gastropods display anything but uniformity in their reproductive mechanisms. In the majority of species the sexes are separate, that is, each individual is male or female; but in whole groups of them, such as the Pulmonata, the individual is both male and female. This fact of hermaphroditism results in phenomena which in the higher vertebrates would seem extraordinary. In these hermaphroditic forms mutual impregnation between two individuals may take place; that is, each of the two may function as both male and female at the same time and thus fertilize the other. In most hermaphroditic species, however, one indivdual assumes the role of male and the other that of female during mating. Sometimes a string of *Limnaea* can be seen thus united, each individual serving as male to one and female to the other of its adjacent neighbors.

Several species of *Limnaea* have been known to reproduce parthenogenetically; that is, without mating.

In by far the larger number of gastropod species in which the sexes are distinct it is impossible to discover the sex of an individual by examining its exterior. However, in some species, the opercula, the radula teeth, the feet, or the tentacles differ sufficiently in the two sexes to distinguish them; or the two may differ in size. The female of *Lacuna pallidula*, for example, has ten times the bulk of the male.

Internal fertilization is not the universal rule in gastropods, but depends on the presence of an intrusive organ. Such species as lack this organ cast their sperm into the sea, where the ova are also discharged; and if the sperm comes in contact with the ova, it fertilizes them. Internal fertilization is the rule in all land mollusks.

Another phenomenon sometimes observed in certain gastropods in which the sexes are distinct is that of delayed fertilization; that is, part or all of the quantity of sperm received by the female at any one time may be stored for later use and may even serve to fertilize suc-

cessive batches of ova developing at widely spaced intervals of time. For such storing of the sperm, some species of Gastropoda have a sperm receptacle connected with the oviduct.

Other organs accessory to the reproductive system that may be present in gastropods of distinct sex are the albumen gland, which furnishes the eggs with food material, and the shell gland, which secretes the covering of the eggs.

But some of the hermaphroditic gastropods have an accessory to the reproductive system of a remarkable sort. This is the dart sac, which contains the love dart—a dart-shaped, tubular shaft of carbonate of lime. This dart, when shot out, is used to inflict punctures and thus produce excitement in mating.

Gastropods, like all other mollusks, reproduce by means of eggs. These eggs may be laid or they may be stored in brood pouches within the parent to undergo further development.

In the manner in which they deposit their eggs and in the number of eggs to a batch, the various species of gastropods show their customary diversity. Thus a single female of the nudibranch genus *Doris* is said to lay from 80,000 to 600,000 eggs to a batch. At the other extreme are the pulmonate land shells: at least, one female of the species *Arion ater* is said to have laid 477 eggs in 480 days. *Helix aspera* lays from 40 to 100 eggs in nests or little hollows at the roots of grass. *Cerion* (Plate 99), a genus of West Indian land mollusks, usually deposits its eggs singly, also at the roots of grass. Many of the Philippine tree snails deposit a single layer of eggs on leaves of the trees they inhabit, whereupon the leaf curls up over the eggs and affords them protection.

The eggs may be deposited singly (Plate 100). In many species, however, they are included in capsules—many eggs to each capsule— and these capsules in turn may be deposited either singly or in groups or chains (Plate 101). Some

pelagic species, like *Ianthina* (Fig. 59, lower), make a raft by secreting certain substances that congeal when they come in contact with the water. To the underside of the raft the eggs are then attached. In most marine and

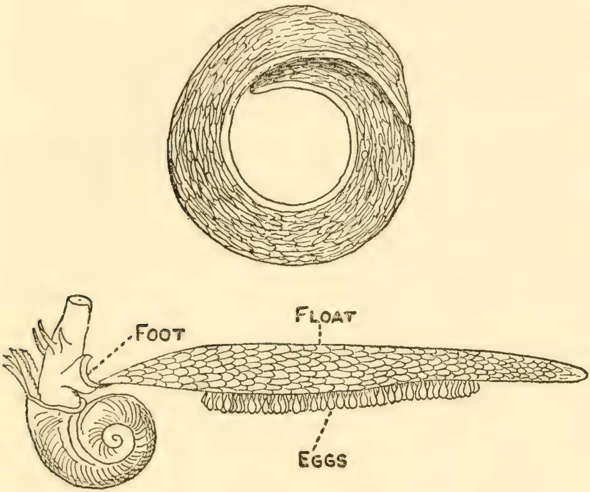


FIG. 59. Upper, spawn of a species of *Natica;* lower, *Ianthina fragilis* and its spawn. After Cooke, and Quoy and Gaimard

fresh-water egg-laying species the egg or capsule is more or less leatherlike; in some of the land forms, however, it is incased in a calcareous test, not unlike that of birds. *Natica* makes a case of sand agglutinated by copious mucus, into which the eggs are dropped (Fig. 59, upper). The sheet curls in a ringlike form.

Development of those species in which the eggs are cast into the sea and there fertilized usually progresses in an orthodox manner; that is, the young animal passes through the several larval stages already discussed in

connection with the Pelecypoda. In the land gastropods a syncopation of these stages usually occurs, and the offspring emerges from the egg or brood pouch in a stage far in advance of the larval forms observed in the marine species. The extent of deviation in the various groups is great.

Gastropods obtain their impressions of the external world by one or another of the senses of touch, smell, sight, and hearing. The entire bodily surface of these animals, and especially that of the foot, is sensitive to touch; but they also have a pair of special organs which seem to be devoted exclusively to this sense just as eyes are devoted to sight. I refer to the tentacles, which are such a marked character of the garden snails. When an individual of almost any species of Cuban helicinids is in movement, it keeps the tentacles in constant vibration, thus furnishing a fine illustration of the animal's dependence upon them.

A personal experience will show how acute the sense of smell in snails may be. I once kept a number of individuals of *Limax flavus* in my house for experimental purposes. Several of them escaped from their cage and crawled beneath the flooring through a mouse hole, coming forth at night to forage. In recapturing them I used a boiled potato as bait, and made the discovery that they got the scent of the potato from a distance as great as seventy-six feet. I have also found, in collecting snails in lakes and streams, that by trailing a lump of suet over floating vegetation from different directions toward a common center and leaving the lump anchored in the center for a day all the aquatic snails will head for the suet. It is undoubtedly the sense of smell that guides them in this reaction. In the same way fish traps and lobster pots, baited with dead fish or carrion of any kind, will gather all the marine mollusk flesh eaters in the vicinity.

Moquin-Tandon has established by experiment that the

Colony of *Cerion casablancae* in a shrub

Eggs and young of *Strophocheilus ovatus*, natural size

sense of smell in helicid mollusks resides in a little knob at the end of the larger tentacles, close to the eye. He found by removing the tentacle in both *Limax* and *Arion* that these creatures lost their olfactory powers.

In most of the marine gastropods the organ of smell seems intimately associated with the breathing organs.

The achievement of the gastropod individual that has an estimated total of 750,000 teeth in the radula, is approached by a certain *Chiton*, which, it has been esti-

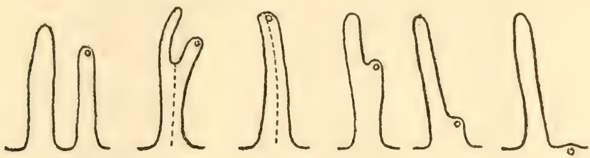


FIG. 60. Relations of the tactile and optic tentacles in the Prosobranchiata. After Lang

mated, possesses no less than 12,000 eyes, scattered over the shell. At the other extreme, just as some gastropods have but a single tooth, so there are species with but a single pair of eyes. The various positions that the paired eyes may take in relation to the tentacles are indicated in Figure 60.

The efficiency of vision among snails likewise varies greatly. Some species seem able to do no more than distinguish between light and dark, while other groups have highly specialized eyes. Many experiments and observations have conclusively shown that some of the helicid land mollusks are shortsighted and that they see better in faint than in bright light; this is undoubtedly an adjustment to the crepuscular habits of most of them. It has been determined, for example, that *Helix* can perceive objects better at a distance of six centimeters in dim light than at four or five millimeters in strong light. Some of the operculates, on the other hand, are comparatively

longsighted, perceiving objects at distances up to thirty centimeters.

Nearly all species of mollusks have a marked predilection either for or against light. Only one species, so far as known, is indifferent.

Eyes are not always necessary to enable mollusks to "see." Experiments have shown that some can perceive

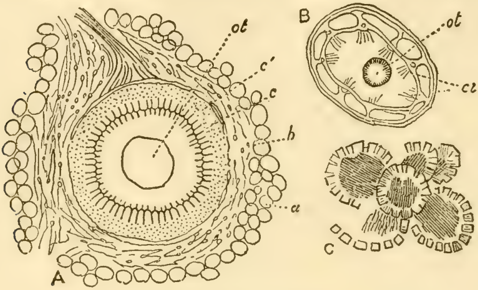


Fig. 61. Otocysts in A, *Anodonta;* B, *Cyclas;* ot, otolith; a, b, c, c′, cellular layers surrounding the chamber; cl, cilia on interior walls of chamber. C, an otolith crushed. After Simroth

variation of light by means of the skin alone and will shun or seek the light without eyes just as they do with them. A few marine mollusks, whether with or without eyes, have also been shown to be exceedingly sensitive to the impact of a shadow.

Many marine gastropods, as well as some land forms, are completely without eyes. In some species these organs are usable in the young stages, but they become overgrown with skin and probably rendered functionless. Incidentally, some of these blind land forms that live in earthworm burrows, such as *Caecilianella*, have recently been accused of nipping the roots of sugar cane. The wound thus produced is said to permit the ingression of bacteria that cause the destruction of the cane.

The organs of hearing in the gastropod consist of a pair of otocysts (ear sacs) containing from one to a hundred or more otolites (ear stones) and nerves which transmit perceptions to headquarters for suitable action (Fig. 61). The sacs are located on the pedal ganglia, and have the appearance of two little white points. However, it is the cerebral rather than the pedal ganglia that appear to function as the nerve center for the hearing organs. The otocysts are entirely closed, they are filled with liquid, and their inner surfaces are lined with epithelium bearing innumerable cilia. There are no auditory canals leading in to the ear sacs from the outer world.

The late Dr. Joseph Leidy, to whom we owe much of our knowledge regarding the sense of hearing in gastropods, has the following to say regarding otolites (which in his day were called otoconites): "They vary in size, are oval in form, transparent, composed of concentric layers of carbonate of lime, and frequently have a small cavity in their centre. During life and for a short time after the death of the animal, the otoconites are endowed with a peculiar vibratory movement, by which they are disposed to accumulate into a mass in the centre of the auditory vesicle. After the cessation of the movement, they become diffused through the fluid of the vesicle."

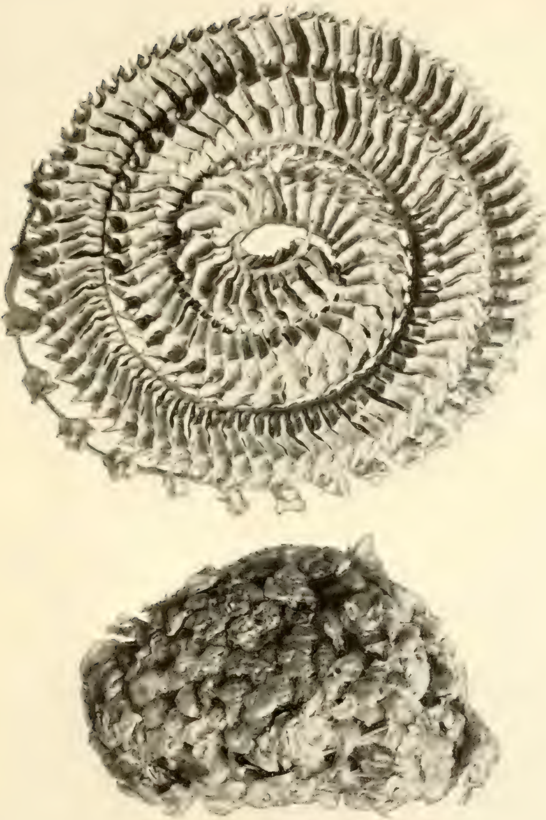
To what extent the gastropods can actually hear is uncertain. Their hearing organs may be only supersensitive organs of touch which feel vibrations that would produce sound if they came into contact with an eardrum. The sensitivity to sound of gastropods may be somewhat like that of deaf persons, who are often aware of vibrations of greater or less intensity which persons of normal hearing recognize as sound—perhaps as faint as the footfall of a mouse, perhaps as loud as a crash of thunder. Whether it be by feeling or by hearing (as we understand that sense) that the gastropods interpret such vibrations, the presence of otolites and of the rest of the apparatus that suggests hearing seems to prove that they need to

know what is vibrating about them, as well as to know through their ordinary sense of touch what they come into contact with, what changes take place in temperature and moisture, and other factors of environment.

Gastropods in Human Economy

Gastropods are useful to man in more ways than one; and in our discussion of them from this angle it seems well to consider first their value as food. The abalone, or sea-ear, has already been mentioned as a food mollusk; and the snail may be placed in the same category. For in much of continental Europe, as every one knows, snails are considered a delicacy. Their cultivation for the table is no new thing: Cooke points out that it dates back to the time of the Romans. The several species of the genus *Helix* shown in Plate 102 appear in the markets of France today. Cooke gives the following exceedingly interesting account of the history of snail cultivation:

> It was a certain Fulvius Hirpinus who, according to Pliny the elder, first instituted snail preserves at Tarquinium, about 50 B.C. He appears to have bred several species in his "cochlearia," keeping them separate from one another. In one division were the *albulae*, which came from Reate; in another the "very big snails" (probably *H. lucorum*), from Illyria; in a third the African snails, whose characteristic was their fecundity; in a fourth those from Soletum, noted for their "nobility." To increase the size of his snails, Hirpinus fed them on a fattening mixture of meal and new wine, and, says the author in a burst of enthusiasm, "the glory of this art was carried to such an extent that a single snail-shell was capable of holding eighty sixpenny pieces." Varro recommends that the snaileries be surrounded by a ditch, to save the expense of a special slave to catch the runaways. Snails were not regarded by the Romans as a particular luxury. Pliny the younger reproaches his friend Septicius Clarus for breaking a dinner engagement with him, at which the menu was to have been a lettuce, three snails and two eggs apiece, barley water, mead and snow, olives, beetroot, gourds and truffles, and going off somewhere else where he got oysters, scallops, and sea-urchins. In Horace's time they were used as a gentle stimulant to the appetite, for
>
> "'Tis best with roasted shrimps and Afric snails
> To rouse your drinker when his vigour fails."



Egg capsules of *Busycon carica* and *Buccinum undatum*

European edible snails (*Helix*)

Escargotières, or snail-gardens, still exist in many parts of Europe, e.g., at Dijon, at Troyes and many other places in central and southern France, at Brunswick, Copenhagen, and Ulm. The markets at Paris, Marseilles, Bordeaux, Toulouse, Nantes, etc., are chiefly supplied by snails gathered from the open country, and particularly from the vineyards, in some of which *Helix pomatia* abounds. In the *Morning Post* of 8th May, 1868, there is an account of the operation of clearing the celebrated Clos de Vougeot vineyard of these creatures. No less than 240 gallons were captured, at a cost in labour of over 100 francs, it being estimated that these snails would have damaged the vines to an extent represented by the value of fifteen to twenty pipes of wine against which may be set the price fetched by the snails when sold in the market.

According to Dr. Gray, the glassmen at Newcastle used to indulge in a snail feast once a year, and a recent writer informs us that *H. aspersa* is still eaten by working people in the vicinity of Pontefract and Knottlingley. But in this country [England] snails appear to be seldom consciously used as an article of food; the limitation is necessary, for Lovell tells us that they are much employed in the manufacture of cream, and that a retired (!) milkman pronounced it the most successful imitation known.

Gastropods, as well as some pelecypods, are valuable, also, for their shells. Even among modern peoples the shells of certain species have attracted much attention and have had an extraordinary value as curiosities. A century ago, more or less, when public museums with their treasures were not the common institutions they are today, many persons made private collections of natural-history objects of various kinds. In such collections mollusk shells, because of their beauty of form and color, held a prominent place. Certain specimens have brought almost fabulous prices—just how much depending on how nearly perfect they were and how rare. In 1854, in London, a single shell (*Conus gloriamaris*) brought £43 1s. (roughly $215); while at the end of the century a *Pleurotomaria adansoniana* was offered for sale for about £100 ($500).

Many primitive peoples and some not so primitive have used snail shells as currency. Until the end of the last century cowrie shells were an accepted medium of exchange among the natives of British India. About four

thousand shells in good condition are said to have passed for a shilling.

As sources of dyes and inks, mollusks—and particularly gastropods—rank high. The classic source of mollusk dyes is the purple shell, a gastropod which malacologists have recently transferred from the genus *Purpura* to the genus *Murex*. The purple shell contributed the Tyrian purple of antiquity. George W. Tryon, in his *Manual of Conchology*, relates how, according to tradition, this dye first became known. It appears that the dog of a Tyrian nymph crushed some of the mollusks now known as *Murex trunculus* in his teeth, thus staining his mouth purple. The color was so beautiful that the fair nymph expressed to her lover, Hercules, her desire to have a robe of similar hue. Hercules, of course, gratified her, and thus began the use of the mollusk dye.

The Indians of the New World also understood how to extract purple dye from shellfish.

To produce the finest Tyrian purple it is evident that the ancients mixed the dye products obtained from two different species: Pliny gives the proportion of 200 pounds of juice of "Buccinum" and 111 pounds of that of "Pelagia" as suitable for obtaining a beautiful amethyst color, sufficient for fifty pounds of wool. To quote from Mr. Tryon:

> The extent of the Tyrian industry is visible in numerous holes in the rocks, two to three feet deep, containing the breccia of shells anciently crushed in them for the extraction of the dye. The arms of the city as preserved on its medals were the *Purpura* shell, and in the time of Strabo the multiplicity of dye-works unpleasantly affected the air of the vicinity.
>
> The Romans used various species in great quantity for dyeing purposes, and the remains of Murices form vast heaps; indeed, in one case, at Tarento, the mass is so large as to have received the name of "Monte Testaceo." The color was prepared by pounding up small specimens, or by breaking the shells of larger ones and extracting the purple gland. This fluid was mixed with five or six times its weight of water, with twenty ounces of soda to every hundred pounds. Placed in lead or tin vessels the mixture was exposed to the sun for several days,

until the hue desired was obtained, when the wool was simply plunged into it and allowed to remain for a few hours. Under Augustus the dyed wool brought as much as $200 per pound.

It is no wonder that the production of purple dye became a thriving industry among the Romans and remained so until a law was passed which prohibited the wearing of purple to any but the imperial family. This was the deathblow of this industry, which thenceforth rapidly declined and died out so completely that during the Middle Ages the very existence of such a dye was considered fabulous. With the Renaissance, however, when the arts and civilization of the ancients were revived, the method of producing it was rediscovered and for a while successfully practiced. Chemistry, however, has now supplied the world with even more brilliant colors, and this at a great saving in producing the dye.

When we come to consider the ink- or dye-secreting ability of certain mollusks we find inseparably associated with it their ability to throw a "smoke" screen about themselves, using the ink as the "smoke" of the screen. And here the mollusks assume a new significance. For the smoke screen has become a definite part of the defense mechanism of modern warfare, especially by sea; and man may well have copied this idea from the mollusks. A number of species have the power, when annoyed, of throwing out secretions which serve to repel the assailant or produce a screen behind which the fugitive may retreat to safety. If man did copy the idea from the mollusks, he is doubly indebted to them on this count; for, as we have already told, he has long made use, as dye or ink, of the substance they eject to form their screens.

The classic examples of smoke screening among the mollusks are furnished by the squids and octopuses that secrete the original "India ink." These mollusks belong to the order Cephalopoda. But there are screen throwers among the Gastropoda, also. The members of the family Aplysiidae, which include the "sea hares," can eject a

purple liquid in sufficient quantity—as I have observed in Philippine, West Indian, and Mexican waters—to so discolor a tub of water as to hide the animal completely. Another gastropod screen thrower is the little pelagic violet snail *Ianthina*, which, when disturbed, exudes a protective cloud of violet ink. *Ianthina* plays a leading role in an amusing story which Doctor Simpson, one of our veteran malacologists, tells on himself. Once while serving in the Navy, Doctor Simpson went on shore all decked out in white. So arrayed he came unexpectedly upon a stranded colony of *Ianthina*, and in his enthusiasm he filled all his pockets with them. But a clammy feeling soon dampened his enthusiasm, and he looked down to find his fine white suit streaked with violet where the ianthinas had discharged their ink. Our indefatigable collector had changed color to such an extent that he had to remain in hiding until nightfall, when, under cover of the darkness, he returned to his ship.

But these various relations of gastropods to man (other than as food) are secondary and incidental when compared to their relation to him as carriers of harmful germs. As contributors to human diseases they loom large on the horizon of millions of people. Mollusks do not attack man directly, but serve as essential intermediate hosts to a number of man's death-dealing enemies; that is, these enemies, called flukes, must find a mollusk in which to pass certain stages of development or else they die. All trematode flat worms (class Trematoda) are believed to require a mollusk as an intermediate host in which to undergo a part of their development. There is an endless variety of these worms, and our knowledge leads us to believe that probably all species of vertebrates entertain within their bodies one or more kinds of them.

Man is no exception to this rule, but is rather unusually plagued with trematodes. The cosmopolitan habitat of man has attracted to him the parasites of all the world.

At least he enjoys the distinction of having more kinds of them than are known in any other one species of animal.

To understand the role played by mollusks in undermining human health, we must know something of the life cycle of a fluke. To describe this cycle I shall select as a concrete example the best known and most studied species—*Fasciola hepatica*, even though it is one of the least important flukes so far as its direct effect upon human health is concerned. Indirectly it does affect man's interests, however, since at the present time it is held responsible for the destruction annually in the United States of about twenty million dollars' worth of sheep livers.

The adult worm normally resides in the sheep's liver. The eggs pass into the bile passages, then through the bile duct into the intestines, from which they are eliminated with the feces. To hatch they must be immersed in fresh water; and this takes place if the feces happen to be dropped into a pool or stream or if the eggs are washed there by rain. The larva, slipping from the egg, is covered with a ciliated coat by means of which it is able to swim in quest of a mollusk. In America the snail usually chosen is *Stagnicola bulimoides* or one of its subspecies. The larva enters the tissues of the mollusk and loses its cilia. Thereafter, the larva goes through a series of changes until it transforms into not one but many tadpolelike cercaria, which worm their way out of the molluscan host. The tail of the larval fluke aids it to swim to some blade of grass, where it encysts. Sheep, browsing along the water's edge, ingest the grass and likewise the flukes which thus reach the alimentary tract of the definitive host. From this they migrate to the host's liver, where they develop their adult characteristics, and thus complete their life cycle. Some of the cercaria may also be swallowed by the sheep when they are drinking water in which the flukes have been set free. Figure 62 illustrates the life cycle of the fluke.

If for any reason the larva fails to find its intermediate molluscan host, it dies, and this fact has caused man to look for relief from trematode infestation by eliminating

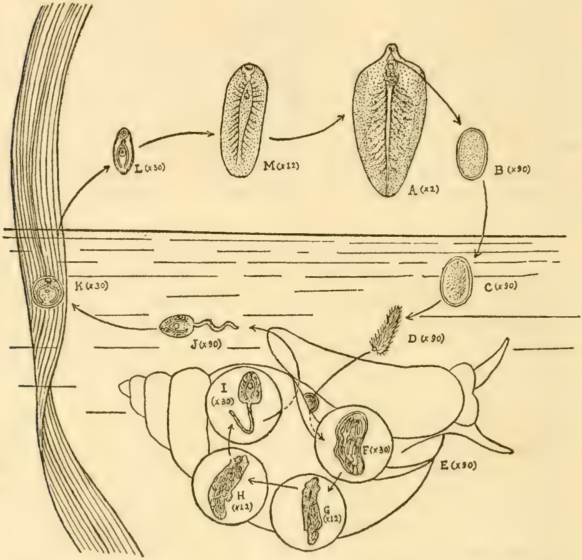


FIG. 62. Diagrammatic representation of the life history of a fluke (*Fasciola hepatica*). A, adult worm in sheep's liver; B, C, egg; D, miracidium, the newly hatched larva in water; E-H, redia and sporocysts—developmental stages in a mollusk; I, cercarian; J, free-swimming cercarian; K, larva encysted on a blade of grass; L, M, development within sheep. After Chandler

the intermediate host and thus preventing development, rather than by medication of infested individuals, only to have them subject to continued attacks. The flukes that infest man may be found in his blood, lungs, liver, or alimentary tract.

Shells of Cuban land snails (*Polymita*), showing the varied color patterns which occur in different species of this genus

The following table lists many of the best known flukes, their intermediate hosts, and their mammalian definitive hosts.

Fluke	*Geographical distribution*	*Molluscan intermediate host*	*Mammalian definitive host*
BLOOD FLUKES: *Schistosoma japonica*	Japan China	*Katayama* *Oncomelania*	Man
Schistosoma hematobium	Southern Europe Africa Mauritius	*Planorbis* *Physopsis* *Bulinus* *Melania*	Man
Schistosoma mansoni	Africa South America West Indies	*Planorbis* *Physopsis* *Ampullaria*	Man
Schistosoma spindale	Sumatra India South Africa	*Planorbis*	Man Cattle
Schistosoma bovis	Sicily Africa	*Physopsis*	Man Cattle
LUNG FLUKES: *Paragonimus ringeri*	Japan Philippines Korea China	*Melania*	Man Dog Cat Swine and others
LIVER FLUKES: *Fasciola hepatica* *Fasciola gigantea*	World-wide	*Lymnaea*	Man Sheep Goat Cattle Swine Cat Dog Fox
Clonorchis sinensis	Japan Korea to French Indo-China	*Parafossarulus* *Bythinia*	Man Cat Dog Swine

Fluke	*Geographical distribution*	*Molluscan intermediate host*	*Mammalian definitive host*
LIVER FLUKES: *Dicrocoelium dendriticum*	Europe Africa Asia North America South America	Unknown	Man Herbivores Omnivores
INTESTINAL FLUKES: *Watsonius watsoni*	Africa	Unknown	Man
Gastrodicus hominis	French Indo-China	Unknown	Man
Fasciolopsis buski	From Formosa through China to India	*Hippeutis Segmentina*	Man Swine Dog
Heterophyes heterophyes	Japan China Egypt	Unknown	Man Dog Cat
Metagonimus yokogawi	Japan	*Brotia*	Man
Amphimerus noverca	India	Unknown	Man
Fascioletta ilocana	Philippines	Unknown	Man
Echinostoma revoltum	Europe	Unknown	Man
Echinostoma malayanum	Malacca	Unknown	Man
Artyfechinostomum sufrartyfex	Assam	Unknown	Man

CHAPTER V

THE OCTOPUSES, SQUIDS, AND THEIR KIN

In the squid, octopus, nautilus, and their relatives, which together constitute the class Cephalopoda, we meet a group which has about it the aura of legend rather than the sober tone of reality. The octopus and its misdeeds share fame and fascination with such legendary beasts as the Minotaur and the sea-serpent (which may in fact be a giant squid's tentacle). Seizing on strange reports of sailormen, story-tellers from Pliny to Jules Verne have dealt freely with a basis of fact sufficiently bizarre in itself.

For there is actually much to excite wonder in these animals—their size, strength, ferocity, and cunning; their beauty, grace, and speed. They are truly the stuff of which legends are made. Even the student of natural history finds them something of an anomaly, so far superior in organization are they to all the other Mollusca.

It may be that the key to the comparatively high nervous development of the octopus and squid can be found in their loss of an external shell. Certainly the only modern cephalopod that retains this shell housing—the chambered nautilus—is a stupid animal as compared with all his shell-less relatives. It is easy to see how release from the confines of a shell would open up new possibilities for bodily development; it is almost equally evident that this bodily development, resulting in increased speed and agility, would bring about an increase of brain power, just as the development in man of that extraordinary tool, the apposable thumb, led to brain expansion.

A shell is, of course, a fortress securing safety to its possessor without mental effort; but when the fortress is taken away a species must compensate for it by greater agility, strength, or keenness, or else submit to extinction. Finally, the energy released from shell-making might very well have gone, in part, into brain formation.

Paleontology teaches us that the cephalopods can boast of a long line of progenitors; indeed, in this respect there are few groups that can compare with them. Millions upon millions of years ago, in Upper Cambrian times, there existed in the seas a small nautiloid animal whose remains contributed to the formation of what is known as the Chau-mi-tien limestone near Tsi-nan, Shantung, China. Its shell is only seven millimeters in length and three millimeters in diameter (Fig. 63, A). This tiny, flexed but noncoiled, chambered nautiloid ancestor of the Cephalopoda (which Dr. Charles D. Walcott has christened *Cyrtoceras cambria*) is ancient enough surely. But it must certainly have been preceded by a long line of other chambered nautiluses; and the order has continued uninterruptedly ever since. The Ozarkian period ushered in a number of families, each with its genera and species. The Canadian period added materially to these; but the greatest differentiation of all took place in the Ordovician and Silurian periods, after which the decline of the order began. This has now reached the point where only four, closely allied species, belonging to the single genus *Nautilus* remain. They all inhabit rather shallow water about the shores and coral reefs of the South Pacific. They seem to cling to the bottom, creeping about there all their lives and never coming to the surface voluntarily. About three thousand extinct species of the suborder Nautiloidea have been named up to the present time, and to this number new forms are constantly being added by the patient paleontologist.

In all the nautiloids the shell is divided into chambers by transverse concave septa, whose margins may be

straight or undulate; a siphuncle, or tube, connects the chambers (Plate 104). The variation in shape and size of nautiloid shells is great. They range from straight to closely coiled cones (Fig. 63, B and C). The shell sculpture, too, presents no end of variations. Whatever the sculpture or size, which varies from the seven-millimeter ancestor to the fourteen-foot cones of *Endoceras*, I have yet to see a nautiloid shell that lacks elegance.

During the Upper Silurian period a new offshoot of the cephalopod stock developed, an offshoot which soon far excelled the Nautiloidea in number of individuals as well as in diversity of structure. This is the suborder Ammonoidea, (so called because of their horns), of which probably more than six thousand species are known (Fig. 63, D, E, and F). In them form, complexity of septation, and external sculpture ran riot and attained an overspecialization which soon spelled exit; for the group reached its highest development in the Upper Triassic and disappeared suddenly and completely at the close of the Cretaceous. In size the ammonoid shells vary from the dimensions of a pea to more than six feet in diameter.

The Nautiloidea and the Ammonoidea belong to the order Tetrabranchiata, and are distinguished by having, as the name implies, four gills. All other cephalopods—and this means all living forms of this class except the four species of *Nautilus*—belong to the order Dibranchiata, the members of which have two gills. The dibranchs are a much younger offshoot of the cephalopod tribe than are the tetrabranchs dating back to the Triassic only, at which time the belemnoids first appeared on the scene.

Evidently it is among the belemnoids that we must seek the ancestors of the squids and cuttlefishes; for the belemnoids were the first cephalopods to have an internal shell, though it was of much greater complexity than is the internal shell of the modern animals (Fig. 64, A). The belemnoids also possessed an ink bag, a character

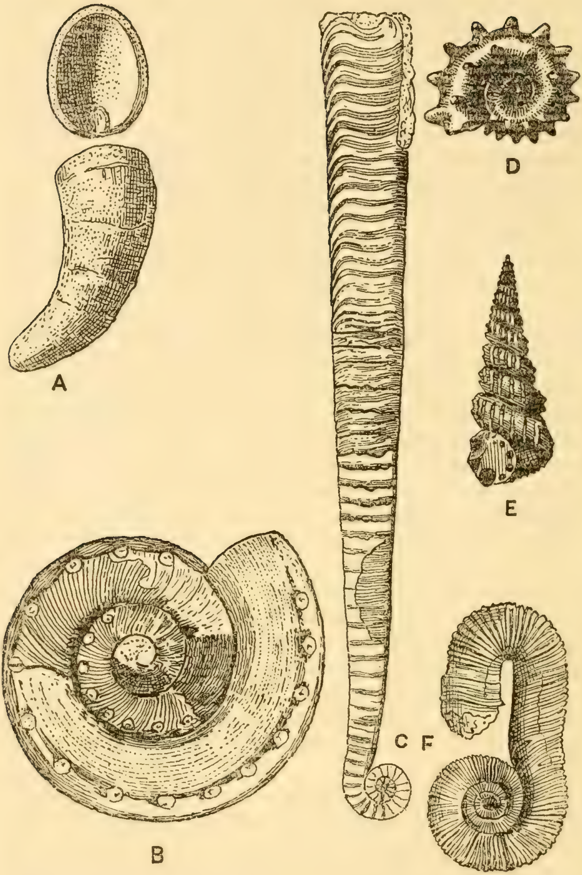


FIG. 63. Fossil cephalopods. A, *Cyrtoceras cambria*, end and side views; B, C, nautiloids; D-F, ammonoids

present in almost all recent dibranchiate cephalopods, but absent in the tetrabranchs. It is quite possible that the belemnoids were as abundant in the seas of their time as their ancestors had been before them and as their descendants are today; but so little fossilizable material did their bodies contain that scarcely anything remained of them after death, and the rocks contain only a meager, scattered, and fragmentary record of their existence.

The belemnoids are the most recent of fossil cephalopods and are followed directly by the modern dibranchs, which include the great majority of the class now found in the seas. As already noted, all living cephalopods fall into the following subdivisions:

Class Cephalopoda
- I. Order Tetrabranchiata
  (contains only one living genus, *Nautilus*, the only cephalopod which still has an inclosing shell)
- II. Order Dibranchiata
  1. Suborder Decapoda
     (contains squids and cuttlefishes)
  2. Suborder Octopoda
     (contains octopuses)

All the tetrabranchs, living and extinct, possess in common at least one invariable character—an external shell. This character has never appeared in any of the dibranchs, all the members of this order, whether living or extinct, possessing either an internal skeleton or none at all. In the squids the shell is embedded in the dorsal part of the mantle and frequently reduced to a mere chitinoid remnant, called the pen (Fig. 64, B-D), from its resemblance to the quill pens of old. In the cuttlefishes the shell remnant is strongly reinforced with calcareous material (Fig. 64, E). It constitutes the cuttle bone of commerce, which is generally considered an indispensable adjunct to a bird cage. The only coiled or chambered shell is found in the decapod *Spirula* (Fig. 64, F); but,

like the shells of all the other dibranchs, that of *Spirula* is internal, being contained within the mantle. The shell of the beautiful paper nautilus—the octopod *Argonauta* (which must not be confused with the tetrabranch chambered nautilus discussed above)—is not a skeletal shell

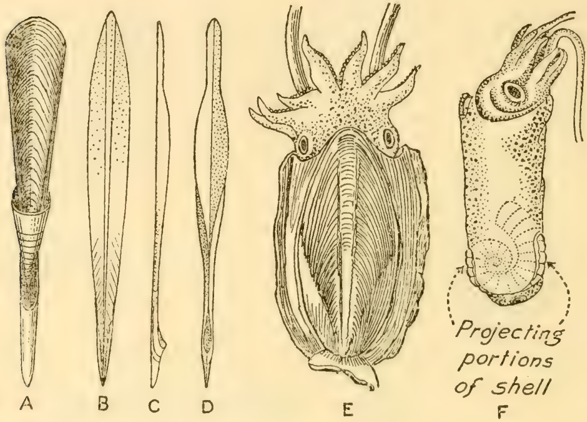


FIG. 64. Internal shells of cephalopods. A, pen of a fossil belemnoid, restored; B, pen of a squid; C, D, pen of a squid from the front and side; E, cuttlefish with mantle removed to show shell; F, *Spirula*. After various authors

at all, but only a case used by the female for the protection of her eggs. Finally, in the octopus the shell has degeneraated into two chitinous rods.

Thus degeneration has been the fate of the molluscan shell in the dibranch cephalopods. These animals have, however, compensated in part for their loss by the acquisition of a cartilaginous skeleton, the tissue of which is very like the hyaline cartilage of vertebrates. This skeleton is but one of the many characters in which cephalopods

approach the vertebrates more nearly than do any other of the invertebrate animals.

The cartilaginous skeleton includes a special box or case for the brain (the braincase) and thus protects that organ; it protects the sense organs also and serves as an attachment for the muscles. So relatively slight is it and so slight are the support and leverage it gives to the muscles that we may well wonder at the beautiful balance of the musculature of the arms. For each arm may be as long and as powerful as a boa constrictor's body—and perhaps more efficient—although it has no bony or cartilaginous support within it, while the boa possesses a complete skeletal framework.

For purposes of description the dibranch body may be divided into the four regions which stand out to the eye of even the casual observer: head, arms, funnel, and trunk or visceral dome. We can speak of a head in these cephalopods with impunity, for this section of the body is well defined and sharply differentiated from the rest. The anterior part of the head, however, is hidden behind the bases of the arms, so that only the posterior portion can be seen externally. Laterally it bears the eyes, which in some forms are stalked, in most sessile, but are prominent in all. The mouth is in the section hidden by the bases of the arms.

Cephalopoda means "headfooted," a term which is certainly an apt one to describe the fringe of arms or tentacles which surround the head in all members of the class. These processes are modifications of the molluscan foot. In the chambered nautilus they are lobelike prolongations of the margin of the head and they bear tentacles—sixty in the male and ninety in the female. The tentacles do not bear suckers; but they are prehensile and adhesive, and each has a sheath into which it may be withdrawn.

The character by which Octopoda and Decapoda are superficially differentiated is indicated in their names:

"eight-footed" and "ten-footed." Unlike *Nautilus*, the dibranch foot is modified into eight or ten muscular, sucker-bearing appendages, or arms. In addition to the four pairs of arms common to both the Octopoda and Decapoda—called the primary arms—the Decapoda have a fifth pair, called the tentacular arms. These are much longer than the other arms and in many species are inserted into pits,

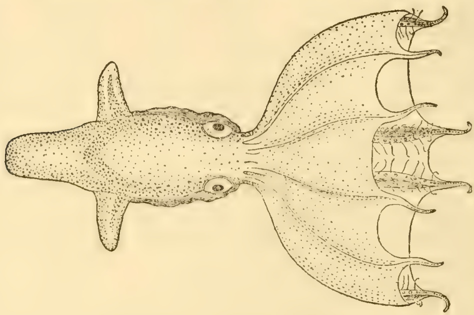


FIG. 65. Octopus in which umbrella connects the arms for their entire length. After Verrill

into which they may be withdrawn. The decapod's fifth pair of arms differs from his four primary pairs in having suckers only at the free, club-shaped end, whereas the primary arms bear suckers along the whole length of their inner surface.

Although the grasping, adhesive, powerful, and versatile processes that surround the head of a dibranchiate cephalopod are the animal's creeping mechanism, the term *arms* describes them better than does the term *feet*. The Octopoda use these processes for creeping more than do the Decapoda, for the Octopoda are principally shore- or bottom-living forms. When the octopod is creeping its body is raised, its head up, its trunk dropped back, and it pulls itself forward chiefly by the contraction of the extended arms. Usually octopods move on the middle sec-

Shell of the chambered nautilus; external view and cross section to show septa

tions of the arms and carry the tips curled up, but they have been seen to advance on the tips, "toe-dancing" along, as it were, in a graceful, airy fashion.

In certain species of Octopoda some of the arms are united at their bases by a membrane, or web; in others, all of the arms are so united; *Eledone* uses this web as a parachute to let itself gently down to the sea bottom. In

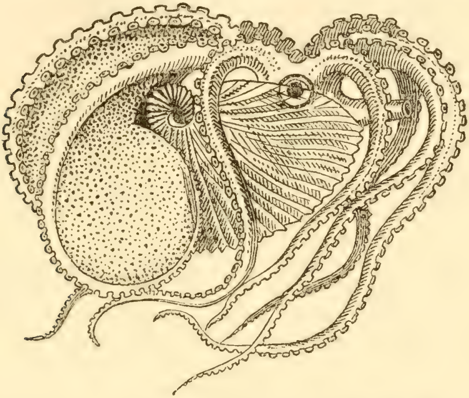


Fig. 66. Female paper nautilus (*Argonauta argo*) swimming. Note the egg case. After Sedgwick

still other octopods—notably *Alloposus* and *Cirroteuthis*—a membrane unites all the arms along their entire length, so that the web with its supporting arms becomes a veritable umbrella, which these genera use in swimming, alternately contracting and expanding it as they move along (Fig. 65).

In another member of the Octopoda, *Argonauta*, the paper nautilus, the terminal parts of the two dorsal arms of the female are expanded into thin membranes, which secrete the shell or egg case (Fig. 66).

In the male of all dibranchs, one of the arms is usually modified for the transfer of sperm to the female. In

some species this arm or part of it becomes detached from the male in mating and is left in the mantle cavity of the female. Cuvier, who first described such a detached arm, mistook it for a parasitic worm and called it *Hectocotylus*. In consequence, the modified arm of all dibranchs is said to be hectocotylized.

The loss of an arm does not mean permanent embarrassment to a cephalopod; for all members of the class have power to regenerate injured arms, just as crustaceans can grow a new claw and lizards a new tail to replace one broken off.

The suckers that line the inner surfaces of the arms are what make the arms of Dibranchiata such powerful grasping organs. There are about eighty suckers on each arm of an average *Eledone*, the largest of which will measure three-quarters of an inch in diameter at the rim. The suckers are sessile in the Octopoda but are stalked and terminate in a horny ring in the Decapoda. When the animal wishes to attach its suckers to an object, the floor of the pit in each sucker is raised while the rim is applied to the object, and then muscular action withdraws the floor of the pit so that a vacuum is created. So powerful is the hold of these suckers that one tentacle alone clinging to a man's hand gives sufficient support to enable a twenty-inch *Eledone* to hang on while it is withdrawn bodily from the water. Whales have been taken with great circular scars in their flesh, made by the suckers of a giant squid in some fierce battle of the seas. Prey of ordinary size must be completely helpless in the clutch of these dibranch suckers.

In certain forms among the dibranchs the suckers on parts of the arms may be replaced by hooks (see Fig. 74, page 344). Also, in many of the Decapoda the outer ring is toothed (Fig. 67).

The cephalopod's chief organ of locomotion—called the funnel—is, like the arm, a modified portion of the molluscan foot. It can be seen attached to the ventral surface

of the cephalopod's head. In *Nautilus* it consists of two lobes rolled round one another to form a tube; but in the dibranchs the edges of these lobes are fused. In the adaptation of the funnel to swimming, nature has again constructed a locomotive machine fit to serve man as a model for his efforts in this direction. Indeed the "rocket" cars,

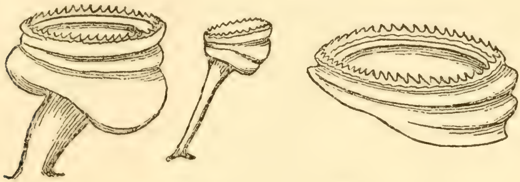


FIG. 67. Suckers of the giant squid with toothed outer rings. The figure on the right is an inch and three-quarters across the rim. Reduced

at present in the experimental stage in Germany, are operated on the principle exemplified in the swimming mechanism of the octopus and his kin. The working of this mechanism may be briefly described as follows: Behind the cephalopod's funnel is the mantle cavity, into which the funnel opens. The cephalopod takes water into this cavity, after which he closes the entry thereto by a special contrivance. Then, by the powerful contraction of the mantle muscles, he forces the water out through the funnel, and the recoils from repetitions of this action drive him backward in rapid jerks. In swimming the cephalopod assumes a position in which the apex of the trunk is in advance of the rest of his body, while the arms trail out behind. The powerful Decapoda, which, unlike the sedentary Octopoda, roam the seas as freely as the whales, swim with great speed and accordingly have a more specialized funnel than the eight-armed group.

All the waste products of the cephalopod's body, as well as the ova and the contents of the ink sac, are eliminated from the mantle cavity through the funnel.

One structure ties the cephalopods anatomically to the bivalves, snails, and all other mollusks—the mantle. This structure forms the soft but tough integument that incloses the trunk of dibranchs like a bag, and terminates posteriorly at the neck in a lip, which opens into the mantle cavity. The shape of this bag varies with the species and may be globular, conic, spindlelike, cylindrical, or lancelike. Furthermore, in one individual the shape may vary to conform to the activity of the animal. Thus the bluntly rounded sac of an *Eledone* at rest becomes stretched out somewhat like the fuselage of a racing plane when the animal is swimming. At the same time a lateral fold of skin becomes prominent and forms a delicate fin, which undoubtedly helps to support the moving body. With the return to rest, the fin again becomes indistinguishable from the body surface.

Many of the powerfully swimming Decapoda have such lateral flukes strongly developed and permanently visible. However, the most curious modification of the mantle sac is undoubtedly seen in *Spirula*, in which it forms a sucker.

The important part the mantle cavity plays in the swimming mechanism of cephalopods has already been mentioned. This cavity is deep and spacious and contains the gills (four in the *Nautilus*, two in the dibranchs), the anus, the ink sac, the paired kidney openings, and the genital duct. To maintain a fresh supply of water flowing over the comblike gills and to expel the excrementitious matter through the funnel the mantle muscles contract regularly.

Judging from observations made on a specimen of *Eledone* in an aquarium, there appears to be no constant rate of breathing in cephalopods. The rate fell as low as six respirations a minute when the animal was in repose and rose to sixteen a minute when it was agitated. A female *Octopus vulgaris* has been observed to breathe thirty-four times a minute while watching over her eggs.

So much for the general make-up of cephalopods as seen from the exterior. It is not so easy to give a comprehensive picture of their internal anatomy without lapsing into technicalities. However, the very interesting feeding habits of cephalopods furnish a favorable introduction to an account of their digestive system.

All the Cephalopoda are carnivorous—a fact which has contributed materially to their fearsome reputation. Many forms appear to subsist principally on crustacean food, though they prey on many other kinds of animals, also, including other mollusks, and when more than ordinarily hungry they have no inhibitions to restrain them from cannibalism. Probably no animal of available size in the seas is safe from one species or another of this class, whereas their own ferocity, speed, and strength render the cephalopods, when adult, immune to all but a few enemies.

The dibranchs display remarkable intelligence in the capture of their food. A cuttlefish has been seen to stalk a prawn until within striking distance, when he would shoot out his two long tentacles and grasp his victim, transferring him instantly to the suckers of the shorter arms. Octopuses will creep along in the wake of scuttling crabs or swim after them until they can conveniently drop on them from above. The prey is rendered immediately helpless by the spreading arms of the cephalopod. Sometimes an octopus will capture several crabs in rapid succession, holding those already caught helpless in its suckers while pursuing the others.

The shrift of a crab after capture by a cephalopod is short. The crustacean's legs are torn away, the carapace is lifted—probably by the mollusk's beak—and the body consumed from the ventral side.

Octopus vulgaris feeds chiefly on mussels. These he collects in his nest in groups of fifteen or twenty and then eats. Presumably he opens a mussel by attaching some

of his suckers to the two valves of the shell and then applying pressure until the valves give way.

The arms transfer the food to the mouth, which is within the circle of arms and is itself circular in shape. The entrance to the mouth is surrounded by a lip and is armed—just inside the lip—with two powerful chitinous jaws, whose shape curiously resembles that of a parrot's beak reversed; that is, the lower or ventral jaw (which is the larger) protrudes beyond the upper and in the act of biting works outside the upper (Fig. 68). These jaws bite vertically with great force, tearing up the food as it is held by the suckers.

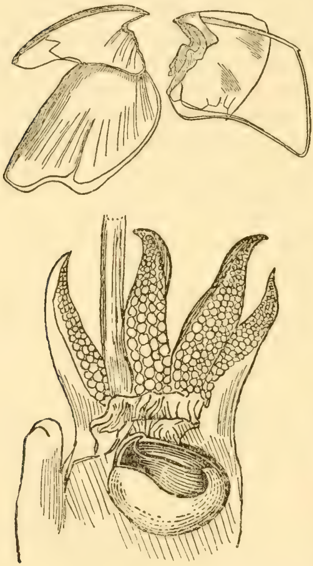


FIG. 68. Jaws of cephalopods. Upper, jaws of the giant squid; lower, jaws of *Sepia* in place and closed, several of the arms having been cut away. After Cooke

Inside the cephalopod's jaws we meet again that typically molluscan organ, the radula—a broad, toothed, chitinous ribbon lying on the upper surface of the tongue. The tongue supplies the energy which moves the radula back and forth, imparting a rasping action to the structure. The teeth of the radula are large; each row usually bears a central or rachidian tooth and from two to four lateral teeth, depending on the species. This organ further grinds the food cut up by the jaws and passes it on through the esophagus

to the well-developed stomach, various glands pouring their digestive secretions over it during the passage. The stomach, in *Eledone* at least, is a muscular grinding organ suggestive of a bird's gizzard.

Digestion is completed in the intestine with the aid of other secretions; and the waste products are then passed to the anus, which, as has been stated, opens into the mantle cavity. From here they are expelled through the funnel.

In all living cephalopods except *Nautilus* and *Cirroteuthis* there is a gland opening into the anus which secretes ink—a thick, dark-brown liquid, a few drops of which will color a large volume of water. Adult octopuses generally throw out the ink screen when at rest and then attempt to escape behind it; but they may discharge it while swimming, and more than once. The gland constantly secretes ink, which is stored in a reservoir upon which the cephalopod can draw at will. The ink contains both copper and iron extracted from the blood. Man has long collected this ink, particularly the sepia of cuttlefishes, and used it as a water color.

The higher organization of cephalopods renders inevitable their possession of a more complete circulatory and nervous system than occurs in the other mollusks. Their possession of a cartilaginous protection for the great nerve centers in the head has already been referred to. It is scarcely a misuse of words to call this a braincase and its contents a brain.

The sense organs, which supply impressions to the brain include tactile organs, well-developed eyes, organs of equilibration (the statocysts), olfactory organs (which probably function also as taste organs), and perhaps heat-sensory organs.

The surface of the body of dibranchs is, as a whole, sensitive to touch; although tactile sensibility is specially localized in the arms, as it is in the tentacles of the tetrabranch *Nautilus*.

Nautilus has simple eyes built on the principle of the pinhole camera, having a sensitive membrane in a dark chamber and a minute hole for the entrance of light; but in all the other members of the Cephalopoda the eyes are large and extremely complicated in structure. In large specimens of *Eledone* the diameter of the eye may be as great as an inch, and there is a record of an eye aperture in a giant squid seven inches wide by nine long. The eyeball is protected by plates of cartilage. Within it are two chambers, a cornea, biconvex lens (which separates the chambers), a highly pigmented iris (which encircles the lens), and a highly innervated and deeply pigmented retina. The complex arrangement of the optic nerve known as the optic chiasma has already been discussed.

Eyes of such complex structure must be efficient organs of vision, and observation has shown that those of some species of cephalopods are more powerful and better adjusted than are the eyes of some vertebrates. Miss Isgrove remarks that "*Eledone*, apparently, dislikes a strong light, in which it seems quite incapable of opening its eyes. If a light is brought near during the night, the eye contracts and the animal retreats."

On the sides of the head, in the cephalopods, one below each eye, are located what are considered to be organs of smell. They may be either hollow tubercles or pits and are supplied with sensory epithelium and innervated by a nerve from the frontal lobes of the cerebral ganglion. There is no direct evidence, however, that these organs are olfactory.

The organs by which cephalopods maintain their equilibrium—statocysts—are paired also. In the *Nautilus* they are located in the head, outside the hard brain cartilage, while in the Dibranchiata they are completely embedded in this cartilage. These statocysts are innervated by nerves from the cerebral ganglion, and in the *Nautilus* each contains numerous small calcareous granules, while in the Dibranchiata a single otolith is present.

Deposition of eggs by *Loligo pealii.* Left, female moving on tips of arms just before selecting spot for deposition; right, female in act of pressing egg mass on rock. Modified from Drew

PLATE 106

Egg case of paper nautilus (*Argonauta argo*), showing eggs within

Finally, certain Cephalopoda have scattered over the skin some rather singular structures or organs whose use is not surely known (Fig. 69). These structures are highly pigmented and are provided with nerve endings surrounded by transparent cells, so that they look somewhat like tiny eyes. It is thought that they are sensitive to changes in temperature, for which reason they are usually called thermoscopic eyes.

In their reproductive organs and habits the dibranchiate Cephalopoda present some features which are, like so much else about them, unique in the animal kingdom.

In all members of the class the sexes are always separate, and usually the male is smaller than the female. In *Argonauta*, for example, the female may be fifteen times the length of the male. It is in this genus, also, that the female secretes a shell, spiral in shape, in which to carry her eggs.

Of other external characters differentiating the sexes in dibranchs the most reliable is undoubtedly the hectocotylized arm of the male. Hectocotylization is the name given to the special modification of one arm,

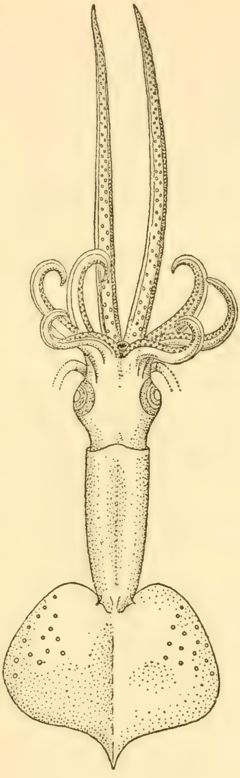


FIG. 69. *Chiroteuthis grimaldii*, showing heat-sensory organs as round spots on fin. The animal's tentacles are indicated by broken lines. After Joubin

in the male dibranch, for the transfer of sperm to the female. The arm so modified is not the same in all species, being on the right side of the body in some and on the left in others. However, in most species, whether on the animal's right or left side, this arm is either the first, the third, or the fourth arm from the front. Some individuals have more than one hectocotylized arm, and the form the modification takes differs greatly: In some species it consists in a mere reduction (in size and number) of the suckers on the arm; in others it may be so complex that the terminal half of the arm has assumed the shape of a wormlike lash, and it is this lash which may become detached during mating and left in the female's mantle cavity (Fig. 70).

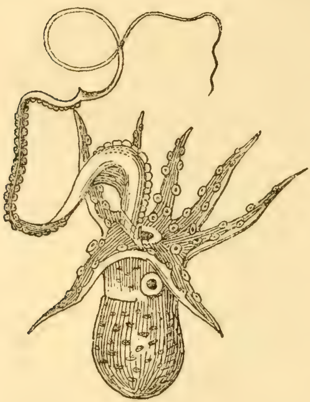


FIG. 70. Male paper nautilus (*Argonauta argo*) with hectocotylized arm. After Müller

The modification of the arm in a certain species must, of course, be consistent with the method of copulation in that species. According to Dr. Gilman A. Drew, there appear to be three methods by which cephalopods copulate. In the first method the hectocotylized arm, charged with spermatophores (sperm capsules), is liberated in the mantle cavity of the female; in the second, the arm does not liberate any portion of itself but is so modified that it can transfer spermatophores by a mechanism within itself to the region of the oviduct, in the female's mantle cavity; and in the third, a slight modification of one arm

enables the male to grasp the spermatophores as they appear at the mouth of the funnel leading from his mantle cavity and transfer them with great speed either to the mantle cavity of the female, or, in certain squids, to the membrane surrounding her mouth, known as the buccal membrane.

To understand this last method, which is that employed by the squid *Loligo pealii*, it is necessary to bear in mind

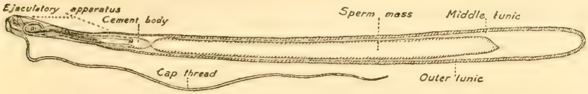


FIG. 71. Spermatophore of *Loligo pealii* completely formed, as taken from the spermatophoric sac. After Drew

that the genital duct of the male opens into his mantle cavity, the exit from which is through the funnel.

In the three genera of cephalopods in which a section of the modified arm is known to be detached and left in the mantle cavity of the female, it appears that the male can replace the detached section.

But the extraordinary feature of the reproductive mechanism of cephalopods is the spermatophore. This is a complex tubular structure, which in some species may attain a length of twenty inches. It contains a mass of sperm, a cement body for attaching this mass to the female, and an ejaculatory apparatus for extruding it (Fig. 71). Ejaculation, which in *Loligo pealii*, at least, apparently begins at the moment of extrusion of the spermatophore from the funnel, seems to require about ten seconds.

Fertilization of the egg may take place, apparently, either in the mantle cavity of the female, or, in certain species, in her buccal membrane. In *Sepia* and *Loligo*, for example, the female has a pocket in her buccal membrane in which sperm masses may be stored (if they are

not deposited in her mantle cavity) while the eggs are being extruded from her funnel.

When the female squid deposits her eggs they are embedded in strings of a jellylike substance which is both soft and sticky. She attaches these strings, or racemes, to

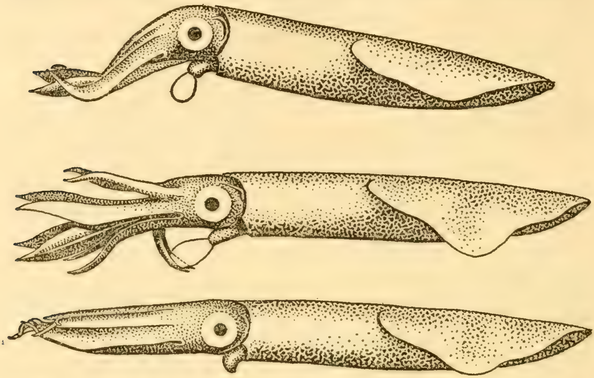


FIG. 72. Extrusion of the eggs in *Loligo pealii*. Upper, female at rest with the egg string beginning to protrude from the funnel; middle, female after she starts to swim, reaching for the egg string with dorsal arms; lower, swimming female, holding the eggs between her arms. After Drew

the submerged surface of some convenient object, a feat which she accomplishes by grasping the object with her arms and then drawing her body down tight so as to crowd the string of eggs against the object (Plate 105). Before attaching them she holds the eggs between her arms for about two minutes, molding them into a cone-shaped mass and perhaps fertilizing them from her sperm receptacle at the same time (Fig. 72). The squid always lays several clusters of eggs and prefers to attach them where others have already been attached.

The eggs of *Eledone* are inclosed in a semitransparent horny egg case, one end of which is drawn out into a

string and attached to twenty-five or thirty similar egg strings (Fig. 73). One female deposits about thirty of these racemes—eight hundred eggs, more or less—during a spawning. *Eledone*, also, like *Loligo*, attaches her egg racemes to some submerged object by pressing them against it with her body.

Argonauta, of course, deposits her eggs in her specially formed, shelly egg pocket, the like of which no other cephalopod possesses.

The eggs of the cephalopod differ from those of all other mollusks in their mode of development; for the young cephalopod passes through no larval stages in the egg but hatches in the form of the adult. The egg is large and heavily charged with yolk.

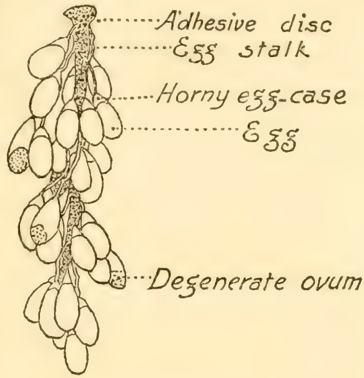


Fig. 73. Egg string, or raceme, of octopod *Eledone cirrosa*. After Isgrove

To what extent the female cares for her eggs during incubation is not known for most species of cephalopods. Cowdry reports that females of the species *Octopus vulgaris* living in an aquarium in Bermuda, after laying their eggs, attached them to the wall of the aquarium and then attached themselves to the wall, also, in such a position as to cover the eggs. A female rarely left her eggs until they were hatched—not even to obtain food; but she contracted her mantle from time to time and thus kept the water in circulation about her. In one instance another octopus so persistently annoyed one of the brooding

females that she deliberately left her nest and killed her tormentor. When the young octopuses began to escape from the egg capsules the females became greatly excited and would dash at a man's hand inserted in the tank. At this time, also, they pulled down most of the eggs from their place of attachment and scattered them about.

It is hard to resist the conviction that the cephalopods have no rivals in the animal kingdom in the variety of startling adaptations they possess. Two more of these adaptations must be referred to before we leave the discussion of cephalopod anatomy and characteristics; namely, the capacity of dibranchs to change color and the capacity of certain species of dibranchs to emit light.

Of the Octopoda, Cowdry says that they are remarkable "in that they exhibit more vivid, complicated, and rapid color changes than do any other members of the animal kingdom" (Plate 107). These alterations in color result from the movements (expansion and contraction) of the chromatophores, or pigment cells, which are distributed in the superficial layers of skin over the whole surface of the octopod's body. Scattered through the skin, also, are light-reflecting cells of a yellowish color, called iridocysts, which cause a peculiar iridescent shimmer. The fine granules of pigment in any single chromatophore are of the same color, but the many chromatophores are often colored differently. Thus it comes about that an individual of a certain cephalopod species may, by expanding all its color cells, approximate a rainbow in the arrangement and shading of its colors.

The dilation or contraction of the chromatophores is effected by muscular radial processes, which connect the color cells with the surrounding skin musculature, and these processes in turn are innervated by nerves communicating with the brain. This very elaborate mechanism in the skin of cephalopods is well calculated to produce a changing color pattern—a pattern whose patches of color are at times sharply defined and at others merge

imperceptibly one into another, their various colors mingling harmoniously to form new shades, which in themselves are not constant but vary from time to time.

Now as to what causes the various color changes in dibranchs: It appears that impulses sent from the central nervous system to the chromatophores are responsible for all the color changes, though there may be simple pulsations of the chromatophores unconnected with the central nervous system. Furthermore, there is a remarkably delicate adjustment in cephalopods between the eye and the chromatophores; that is to say, the change of color in an animal to correspond with its background "depends solely upon the excitation of a reflex arc which passes from the retina through the optic nerve to the brain and thence by the various nerve trunks to the chromatophores." It has been shown that the degree of rapidity with which an octopus or squid can change color and the degree of brilliancy of the colors he assumes are commensurate with the degree of development of his eye.

Color changes apparently respond also to the dibranch's emotions; he seems to blanch when frightened and flush a dark color when angered, and such changes are powerful enough to overrule his natural impulse to assume a color which simulates his background and changes with it. The subject is a fascinating one about which much remains to be learned.

As Cowdry gives the octopods first place among animals judged by the capacity to effect vivid and rapid color changes, so Berry is inclined to believe that certain squids exhibit the highest development of the power to produce light known in the entire animal kingdom. Authentic cases of the possession of photogenic qualities in cephalopods seem to be limited to the decapods, among whom it is widespread, though actual luminescence has been observed in only a few species. This paucity of observations may be explained by the fact that most luminescent cephalopods are deep-sea dwellers and that therefore man

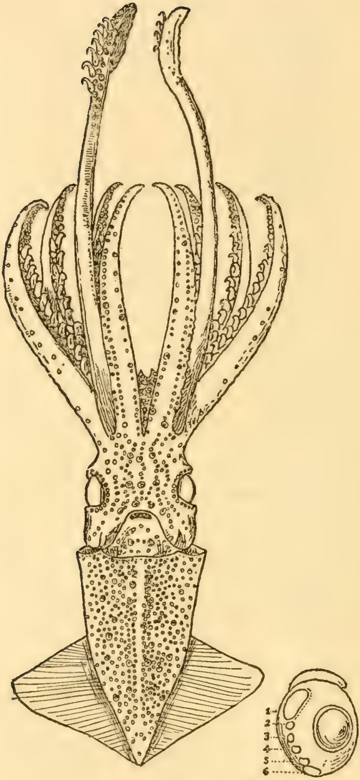


FIG. 74. *Abralia multihamata.* Ventral view of a female, to show luminous organs, and eyeball enlarged, to show luminous organs (1–6). After Sasaki

has few opportunities to observe them.

Photogenic organs may occur in almost any portion of the octopod possessing them, but are more apt to occur in the outer integument both of the arms and of the mantle sac, in the eyeball, or in the mantle cavity (Fig. 74). They are often internal and able to function only by reason of the transparency of the body tissues in a live animal.

Recent discoveries made by the Dana expeditions have revealed that *Spirula*, the curious little dibranch which is distinguished by the possession of a coiled internal shell and by the fact that its mantle forms a sucker at the posterior end, also possesses a photogenic organ in the center of the terminal or sucker disk. It is a small beadlike organ which gives off a pale yellowish-green

A few of the typical color phases exhibited by *Octopus vulgaris*. Above, an irritated animal discharging ink; middle, swimming animals; below, a frightened animal. Modified from Cowdry

light. In contrast to the light which flares up and fades away again, displayed by so many other marine organisms, the *Spirula's* little lamp burns continuously. Schmidt records having seen the light showing uninterruptedly for hours together.

Incidentally, until the investigations of the Dana expeditions, the reports of which were published in 1922, a living *Spirula* was a zoological rarity. The Dana expeditions found them to be bathypelagic, occurring at depths of from 600 to 6,000 feet. Specimens range in size up to one and seven-eighths inches in length of mantle. Their preferred position seems to be head downward so that the light on the posterior end always shines upward. Apparently the gas in the spiral shell tends to keep the posterior end up.

The actual structure of the photogenic organs in cephalopods exhibits great variety, ranging from simple discharging glands and lumps of photogenic tissue to complex bull's-eye lanterns and mirrored searchlights.

As to the color and intensity of light emitted by cephalopods various opinions exist, but that this light can, in some species, be blindingly brilliant and even richly hued there seems no doubt.

Facts and Fancies

Cephalopods have furnished engrossing themes for writers since the days of Aristotle. Much false information has been disseminated about them, a fact that is not to be wondered at when one considers how difficult it is to acquire accurate first-hand data on these wholly marine creatures. The legend of the chambered nautilus sailing gracefully on the surface of the sea dates back at least to Pliny. As a matter of fact the chambered nautilus lives in the tropical western Pacific, usually at depths of a hundred feet or more, and, all myths to the contrary, has never been known to sail the surface of the sea.

Not all of the many recorded stories of encounters

between men and cephalopods will bear the critical scrutiny of the scientist. Most of them are necessarily founded on the tales of seamen. But there is no doubt that octopuses and squids can be dangerous enemies. Cassell's *Natural History* contains a detailed account of an attack made by an octopus on a diver at work on the bottom of the tideway of the River Moyne, in the State of Victoria, Australia, on November 4, 1879. The diver lay flat on top of a large stone, this being the only position in which he could feel under it for a recess in which to place a charge of dynamite. Cassell's quotes the diver as follows:

My arm was scarcely down, however, before I found that it was held by something, and the action of the water was stirring up the loose clay, and therefore I could not see distinctly for a few minutes, but when it did clear away I saw, to my horror, the arm of a large octopus entwined round mine like a boa constrictor, and just then he fixed some of his suckers on the back of my hand, and the pain was intense. I felt as if my hand was being pulled to pieces, and the more I tried to take it away, the greater the pain became, and, from past experience, I knew this method would be useless. But what was I to do, lying in this position? I had the greatest difficulty in keeping my feet down, as the air rushed along the interior of my dress and inflated it, and if my feet had got uppermost I should soon have become insensible, held in such a position, and if I had given the signal to be pulled up the brute would have held on and the chances would have been that I should have had a broken arm. I had a hammer down by me but could not reach it to use it on the brute. There was a small iron bar not far from me, and with my feet I dragged this along until I could reach it with my left hand. And now the fight commenced; the more I struck him the tighter he squeezed, until my arm got quite benumbed; but after awhile I found the grip began to relax a little, but he held on until I had almost cut him to pieces, and then he relaxed his hold from the rock and I pulled him up. I can assure you I was completely exhausted, having been in that position for over twenty minutes. I brought the animal up, or rather a part of it. We laid him out and he measured over eight feet across, and I feel perfectly convinced that this fellow could have held down five or six men.

Well authenticated reports exist to prove that squids, also, have attacked men. Verrill quotes the following

extract from a letter written by the Rev. M. Harvey to Dr. J. W. Dawson and later published in the Montreal *Gazette*:

Two fishermen were out in a small punt on October 26, 1873, off Portugal Cove, Conception Bay, about 9 miles from Saint John's. Observing some object floating on the water at a short distance, they rowed towards it, supposing it to be a large sail or the débris of a wreck. On reaching it one of the men struck it with his "gaff," when immediately it showed signs of life, reared a parrotlike beak, which they declare was "as big as a six-gallon keg," with which it struck the bottom of the boat violently. It then shot out from about its head two huge livid arms and began to twine them round the boat. One of the men seized a small ax and severed both arms as they lay over the gunwale of the boat; whereupon the fish moved off and ejected an immense quantity of inky fluid, which darkened the water for two or three hundred yards. The men saw it for a short time afterwards, and observed its tail in the air, which they declare was 10 feet across. They estimate the body to have been 60 feet in length, 5 feet in diameter, of the same shape and color as the common squid, and they observed that it moved in the same way as the squid, both backwards and forwards.

One of the arms which they brought ashore was unfortunately destroyed, as they were ignorant of its importance; but the clergyman of the village assures me it was 10 inches in diameter and 6 feet in length. The other arm was brought to Saint John's, but not before 6 feet of it were destroyed. Fortunately, I heard of it and took measures to have it preserved. Mr. Murray, of the geological survey, and I afterwards examined it carefully, had it photographed, and immersed in alcohol; it is now in our museum. It measured 19 feet, is of a pale-pink color, entirely cartilaginous, tough and pliant as leather, and very strong.

The literature of the past abounds in myths about sea-serpents, the basis for most of which is traceable to the giant squid. For this is the only known animal whose arms can, without distortion, be made to assume a serpentine form. Figure 75, based on the measurements of an actual specimen, shows how nearly a squid's arm may resemble a serpent. The expanded end of one of these long arms, studded with suckers, might easily be mistaken for the bearded or maned head which is usually assigned

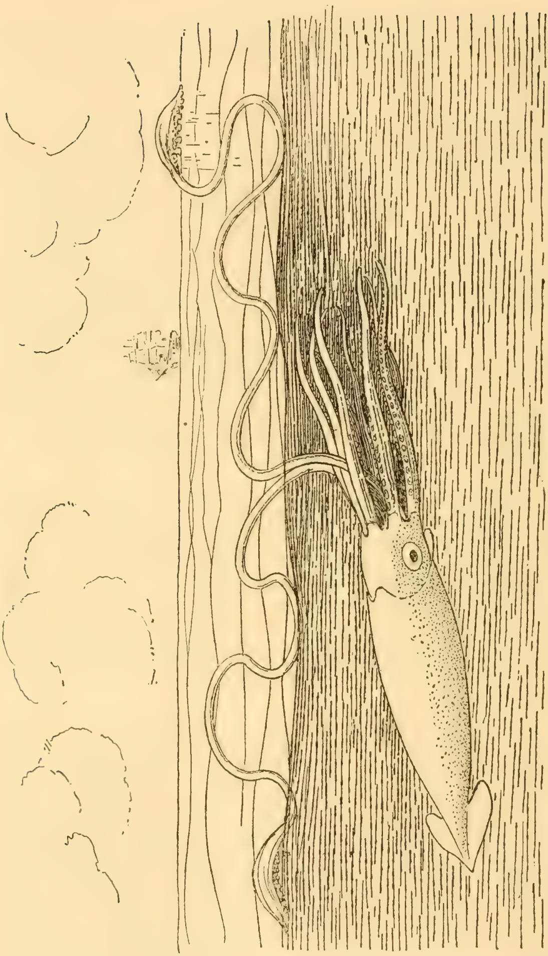


FIG. 75. Giant squid (*Architeuthis princeps*), based on measurements of an actual specimen. Its position suggests how the tentacles may have been mistaken for sea serpents

to the serpent. A momentary glimpse of such a vision at long range would suffice for the untrained mind to create a kraken, kraxen, krabben, korven, ankertrold, soe-horven, haf-gua, soe ormen, horven, aale-tust, or sea-serpent. In further support of this explanation of the origin of the sea-serpent is the very suggestive fact that the known distribution of the giant squids is coextensive with the regions from which the above-named beasts have been reported. It is also interesting to note that the size of these mystic animals has decreased with increased ocean travel and general education.

Measurements made by Verrill himself on many specimens of giant squids caught off the northeastern coast of North America give adequate evidence of the great size which these invertebrate monsters may attain. The largest individual he had examined up to the time of his report was fifty-five feet long over all; its tentacular arms measured thirty-five feet in length; and the length of the body from the tip of the tail to the base of the arms was twenty feet. The greatest length for tentacular arms mentioned in his table is thirty-seven feet and the greatest circumference of the body is twelve feet. The diameter of the largest sucker is given as about two and a quarter inches and the size of the largest eye opening is seven by nine inches.

My own experience with squids has given me a very high respect for their swimming powers. Until I had seen them in their native haunts I had always believed what I had been told about squids; namely, that they were old-fashioned, antiquated relics of the past, whose very method of progression—backward, instead of forward—marked them as unfit to compete with other marine animals. Well do I recall the rude awakening to which I was subjected when I tried to capture some slender loligopsoid squids in southern Philippine waters. I was on board the *Albatross* in the harbor of Jolo. The night was dark and the sea as smooth as glass. We were fishing

with the submarine light, a 16-candlepower electric bulb inclosed in a glass globe. It should be stated here that the sea about Jolo Harbor is one of the richest plankton-bearing areas of water that it has been my good fortune to visit; and where there is an abundance of this microscopic life, there, too, will be found the larger forms that subsist upon it. A swish or two of the light and a quick change of depth at once attracted a cloud of minute forms; then larger animals came, attracted in part by the light and in part by the food. The protozoans were soon followed by worms and crustaceans, whose tangential course would soon have carried them beyond our light were it not that the fascination of a light causes them to curve their path more and more and apparently renders them unable to escape from its charm.

Thus we soon found millions of creatures drawn into a spinning vortex about our light—the "wheel of life," as some one has aptly termed it. New sorts kept coming: small fish of various kinds, a school of sardines dashing madly after the small crustaceans and worms, and still larger and larger fish at greater distances from the light, always preying upon the lesser circle within; now and then even the shadowy outline of a large shark injected itself into the distant reaches of our lamp. It was a mad dance that this whirling, circling host of creatures performed.

Then a new element entered: living arrows, a school of loligopsoids shooting across our lighted field, apparently attracted not so much by the light as by the feast before them. They were wonderful creatures, these squids, unlike anything else there; they shot forward and back like shuttles, with lightning rapidity. Not only that, but they were able to divert their course to any new direction with equal speed. As each of them shot forward, his tentacles would seize a small fish, and instantly he would come to a full stop, only to dart backward like a flash at the least sign of danger. Kill, kill, kill; they were blood-

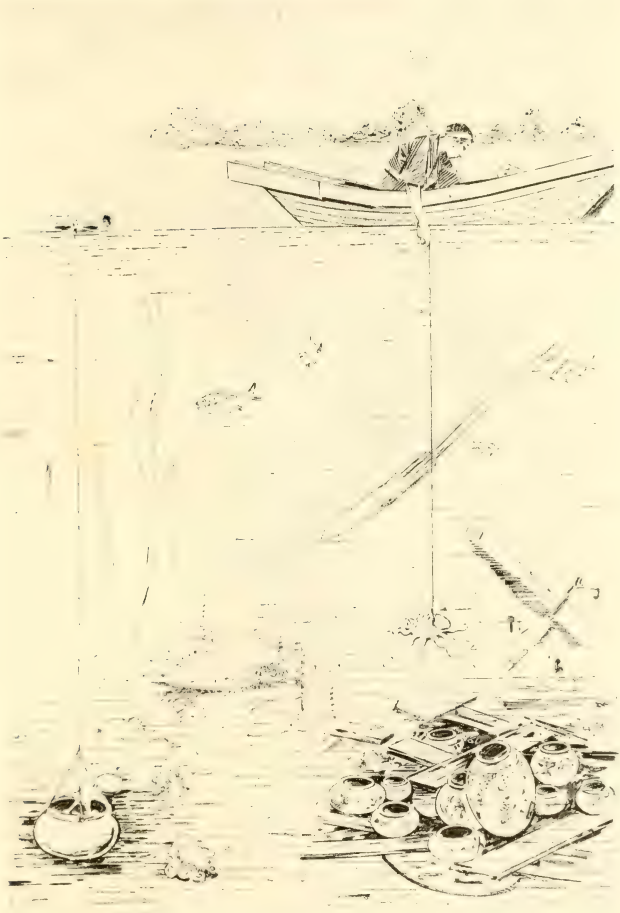
thirsty pirates. A bite in the neck, and the fish was done for; but the sport continued, and, likely as not, one fish would be dropped and another seized and dispatched. Never before nor since have I seen anything that appeared to me more beautifully equipped for an aquatic existence than one of these squids. Frequently, very frequently, their impetuous dashes would carry them away above the surface of the sea—flying squids, the pumping of whose siphons produced a popping sound.

I had heard that the Newfoundland fishermen catch squids by using a sinker with a series of hooks attached to it. This they bob up and down in the water, attracting the squids and hooking them. We tried such a sinker on our Sulu squids, but they refused to be hooked. They would dash up to the contrivance and follow it at a safe distance, but they disdained to be caught. They would even snatch the small fish used as a bait from the hooks and make good their escape. Even the expert jiggers aboard failed to catch them. Some one had the bright idea of floating a pocket net from the beam, in which it was expected that the squids would enmesh themselves. This was tried, but we found that our squids possessed an intelligence equal to their lightning movements in the rapidity of its response to their needs. Not a single one of the thousand or more that composed the school became enmeshed. But they seemed to enjoy shooting through a hole in our seine; and it was as comical as it was wonderful to see their arrowlike forms dart through this opening—not more than eighteen inches in diameter—as swiftly as if fired from a rapid-fire machine gun. Now and then the whole school would come near the surface, pause, and then sink to a depth beyond our range of vision. Again the school would line up on the far side of our net, sink below it, and shoot up to the near side, to make an assault upon the small fish fry which attempted to escape by breaking from the water. We finally did capture a few of these dare-devil fellows; but we had to get them one

by one, by watching the speedy flight of an individual near the surface and quickly casting our dip net ahead of him. The efforts of half a dozen fishermen for three nights running, however, yielded only a couple of dozen specimens.

For all their size, ferocity, and speed, cephalopods have their enemies, not the least of which is man. In many countries and since very ancient times the octopus has been considered a choice morsel. The Greeks and Romans considered it the finest food furnished by the sea. Pliny tells us that the gourmands of Rome ate every variety of octopus known in the Mediterranean. The cooks baked the creature in a sort of big pie, cutting off the arms, and filling the body with spices; and they were so careful in their preparation of the animal for cooking that they used pieces of bamboo for drawing the body, instead of iron knives, which were supposed to communicate an ill flavor to the delicious morsel. How highly the cuttle was esteemed by the Greeks is evident from a story told of Philoxenus of Syracuse, who, desiring a delicious dinner, caused an octopus of three feet spread to be prepared for the principal dish. He alone ate it, all but the head, and was taken so sick in consequence of his surfeit that a physician had to be called. On being bluntly told that his case was desperate, and that he had but a few hours to live, Philoxenus called for the head, also. When he had eaten the last bit of it he resigned himself to his fate, saying that he left nothing on the earth which seemed to him worthy of regret.

The methods employed in capturing octopuses vary with the people who pursue them. Aristotle tells us that the cuttlefish and the octopus may be caught by bait. The octopus, in fact, clings so tightly to the rocks to which he invariably attaches himself that he can not be pulled off, but holds fast even after a knife has been used to sever him from his stronghold; and yet, if you apply fleabane to the creature, he lets go his hold at the very



Japanese fishermen using octopuses to recover sunken porcelain

smell of the stuff. This last procedure is still commonly practised on the Mediterranean shores, where either fleabane or the even handier drug, tobacco, serves to induce the obstinate cephalopod to surrender.

Along the Tunisian coast octopuses are taken in deep water by means of earthenware jars strung together and lowered to the bottom of the sea. After a certain number of hours the jars are raised, and frequently from eight to ten octopuses are found in each jar. Earthenware drain pipes are similarly used in shallower water. The animals are attracted by white and by smooth and bright substances, a predilection of which the native fishermen take full advantage.

Incidentally, the prosperous season for Tunisian octopus fishermen is during Lent, for then octopus is eaten in considerable quantity by devout Greek Catholics instead of the prohibited meat.

The simplest method of capture, probably, is that used by the Filipinos. I recall my first octopus hunt with them one dark night in the southern islands. Our ship, the *Albatross*, lay peacefully at anchor some half a mile off a Moro village, whose dim outline was faintly silhouetted against the sky. We had just finished our dinner when we noticed a torchlight procession from the village down the sand spit that fringed a reef. The procession soon changed from an orderly march to what, at the distance from which we viewed it, seemed some wild ceremonial dance. Our curiosity thoroughly aroused, we lowered a boat and soon joined the party. It was made up of men and boys, each clad in the conventional G-string costume and provided with a torch four to six inches in diameter and probably ten to twelve feet in length, made of segments of dried, split bamboo. Each native carried his torch on the left shoulder and held it by the left hand with the lighted end in front. The right hand was reserved for a bolo or spear. The light of these torches penetrated the shallow water and revealed the

luckless octopuses, which seemed to have forsaken the secure caverns of the reef and to have gone a-hunting on the shallow flats within. They are curious creatures, and their humped-up attitude and large eyes render them rather comical at such times. But there is little time allowed for the contemplation of any one particular animal, for a native bolo or spear brings him to land to be strung promptly on a rattan string.

We secured enough specimens that night to enable us to spare some to the cook, for Ming assured us that they were "vely good." So they were—or rather, I should say, it was—for I chewed a single tentacle during the greater part of the following forenoon and relinquished it only, and that with regret, when my jaws, aching from overexertion, refused to operate any longer.

On the island of Guam we found an entirely different method in use. Here we watched the natives fishing for the octopus on the inside of the slender reef that stretched from Cabras Island toward the steamer entrance to the beautiful Apra Bay and Harbor. The natives here tie a large, repulsive-looking holothurian to a line with a sinker attached, which is then lowered among the crevices of the reef. If it finds a cavity containing an octopus, the latter at once leaves the premises and is then easily speared by the man in the bow of the canoe. There is evidently something about the holothurian that is extremely distasteful to the octopus. It is quite a picture to see these fishermen working in the very teeth of the pounding surf with a craft so frail that one constantly wonders how they manage to keep it from being dashed to pieces.

Dr. H. M. Smith writes as follows of the manner in which the Japanese fishermen catch these animals:

The octopus or devilfish is abundant and is an important food product in Japan, although my personal opinion is that it does not appeal strongly to the American palate. The octopus is caught in various ways, one of the most interesting of which is by the use of earthenware pots, which are lowered to the bottom by means of cords;

they are entered by the octopuses, which, having insinuated themselves, are reluctant to withdraw, so that the pots may be pulled to the surface before the animals try to escape. I bring up this fishery in order to refer to a very ingenious corollary, which was first mentioned to me by a professor in the Imperial University and later verified by myself. More than a century ago a vessel laden with a very valuable cargo of porcelains from Korea destined for the imperial household was wrecked in the Inland Sea; the captain and other officers did what seems to have been a favorite amusement of the olden days; namely, they committed suicide just before the vessel sank in deep water. Recently the fishermen have been recovering pieces of this pottery, which now has an appreciated value, by tying strings to octopuses and lowering them in the vicinity of the wreck. The animals enter the vessels and retain their hold of them while being drawn to the surface. Several pieces of this porcelain which I saw were gems, seeming but little the worse for their prolonged submergence.

In western countries the principal use made of cephalopods is undoubtedly as bait. The ancient Mediterranean fishermen used to roast the fleshy parts of the cuttlefish for this purpose, but the American cod fisherman salts it. Some years ago Simmonds wrote:

> The common *Loligo* is the favorite food of the cod and is therefore itself fished for bait. One-half of all the cod taken on the banks of Newfoundland are said to be caught by it. When the vast shoals of this mollusk approach the coast, hundreds of vessels are ready to capture them, forming an extensive cuttle fishery, engaging 500 sail of French, English, and American ships. During violent gales of wind hundreds of tons of them are often thrown up together in beds on the flat beaches, the decay of which spreads an intolerable effluvium around. They must themselves be consumed in enormous numbers, for it has been estimated that a single squid will lay in one season 40,000 eggs.

The annual catch of squids is said by the United States Bureau of Fisheries to amount to about three million pounds, estimated to have a value of about $43,500. Sixty-six per cent are caught in traps in moss, chiefly about Cape Cod, though many are obtained in this manner along the coast all the way from Maine to Maryland. Considerable quantities in addition to those noted in the above statistics are obtained by American fishing vessels on the coast of Canada and Newfoundland. On our west

coast squids are caught for food, being chiefly used by the Oriental element of the population. All through the South Seas, the Philippines, and Japan, as well as the adjacent mainland countries, one may see split and dried cuttlefish hung in the stores for sale. In the Mediterranean countries they are usually pickled. The cuttle bone is not only used as an adjunct to the canary's cage, but in powdered form has served as a fine polishing powder, a dentrifice, and an ingredient of medicines. The ladies of ancient days knew it also, for they were accustomed to use the burned product, known to them as pearl powder, as an aid to beauty. In later days this was even improved upon by the addition of a bit of carmine to form the so-called French rouge.

Aside from man the sperm whale is undoubtedly the worst enemy of the monstrous squids; for it is well known that parts of squids are usually to be found in the stomach of a captured whale or that he vomits them out when the whalers take him. And the marks of cephalopod suckers indelibly impressed in the skin of more than one captured whale has proved that the giant mammal does not master his victim without himself suffering pain.

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